

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF FISH AND GAME
BUREAU OF MARINE FISHERIES

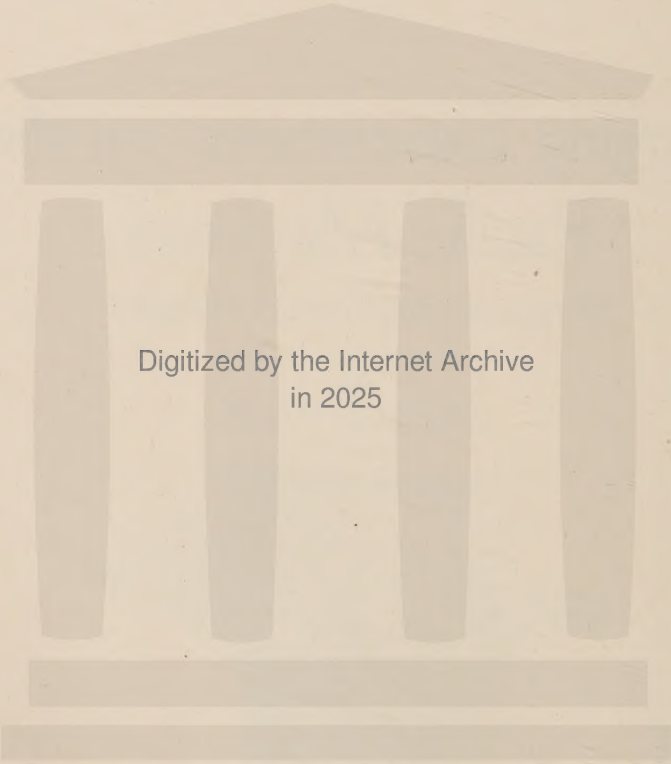
FISH BULLETIN 73

Tagging Experiments on the Pacific Mackerel (*Pneumatophorus diego*)

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The Fisheries Research Board of Canada, through the courtesy of Dr. J. L. Hart, tagged the only mackerel released in the Pacific Northwest. To all those others who helped—marking fish, searching for tags, installing and maintaining cannery magnets, compiling and analyzing the data, or contributing time and effort in many other ways—go our thanks.

DONALD H. FRY, JR.
PHIL M. ROEDEL

January, 1949.

TAGGING EXPERIMENTS ON THE PACIFIC MACKEREL

(*Pneumatophorus diego*)

INTRODUCTION

The Mackerel Fishery

Prior to 1928, the Pacific mackerel fishery was of minor importance, the catch being almost wholly absorbed by the fresh fish trade. Since that year, a large scale canning industry has developed in Southern California with an almost unlimited demand for fish. The bulk of the catch is processed in the Los Angeles Harbor area though large tonnages are handled at Newport Beach, some thirty miles to the south. Small amounts are canned at San Diego and at Ensenada, Mexico, the southern limit of the fishery. In Central California, mackerel are sometimes landed mixed with sardines (*Sardinops caerulea*) caught by the San Francisco and Monterey purse seine fleets. The quantity taken is rarely sufficient to warrant segregation for canning, and the mixed loads are for the most part reduced as "sardines." As a result, there is no record of the actual tonnage of mackerel handled at these ports.

The Southern California fishery for the canneries was at first prosecuted largely by net boats, first the lampara and later the purse seine fleet accounting for most of the catch. Since 1939, the emphasis has shifted to a large fleet of small "scoop" boats. The crews of these vessels, usually two or three men, fish with ground bait and dip the mackerel with a long-handled brail. The total catch has fluctuated widely from year to year with little relation to economic demand. Monthly landings reach a peak in the fall and winter months; there is a period of scarcity, apparently associated with spawning, which usually occurs in the spring but sometimes extends from mid-winter to early summer. For the period covered by this report the season is regarded as commencing in June and closing the following March. Croker (1933, 1938) gives a detailed account of the fishery's development.

The biological range of the species far exceeds the commercial, extending from the Gulf of Alaska southward into the Gulf of California. Mackerel are known to be abundant along much of the Lower California coast and heavy spawning occurs in Mexican waters (Fig. 1). The population is apparently limited north of Central California and does not support a fishery above Monterey Bay.

Fishing Grounds

The mackerel fleet operating out of Los Angeles Harbor (including for this report the City of Long Beach as well as the San Pedro, Wilmington and Terminal Island districts which comprise Los Angeles Harbor proper) exploits a large portion of the waters off Southern California (Fig. 2). The purse seine fleet for both mackerel and sardines ranges

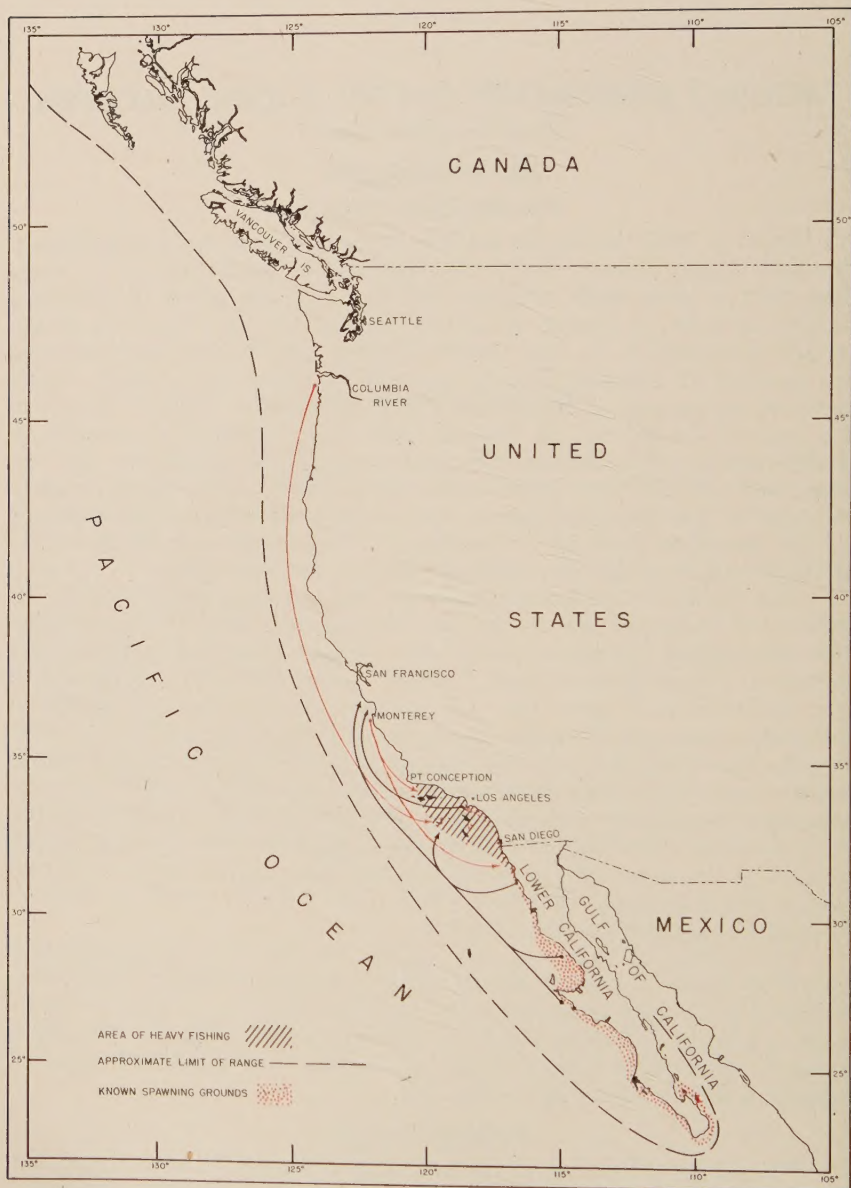


FIGURE 1. Major movements of tagged mackerel. Red lines denote southerly movements; black, northerly. No marked fish were released north of the Columbia River or south of central Lower California. The Gulf of California has not been explored for mackerel beyond the limit of the broken line.

from near Pt. Conception in the north to the Oceanside region in the south, and offshore to the Channel Islands. The scoop fleet covers Santa Monica Bay, the mainland coast as far south as Newport Beach, and offshore around Santa Catalina Island. Virtually the entire catch landed at Newport Beach is made by scoop boats fishing along the mainland coast between Huntington Beach and San Onofre and at Santa Catalina Island. At times this fleet will work south to Oceanside. Fishing at San Diego is carried on within twenty-five miles of port and is generally of minor significance.

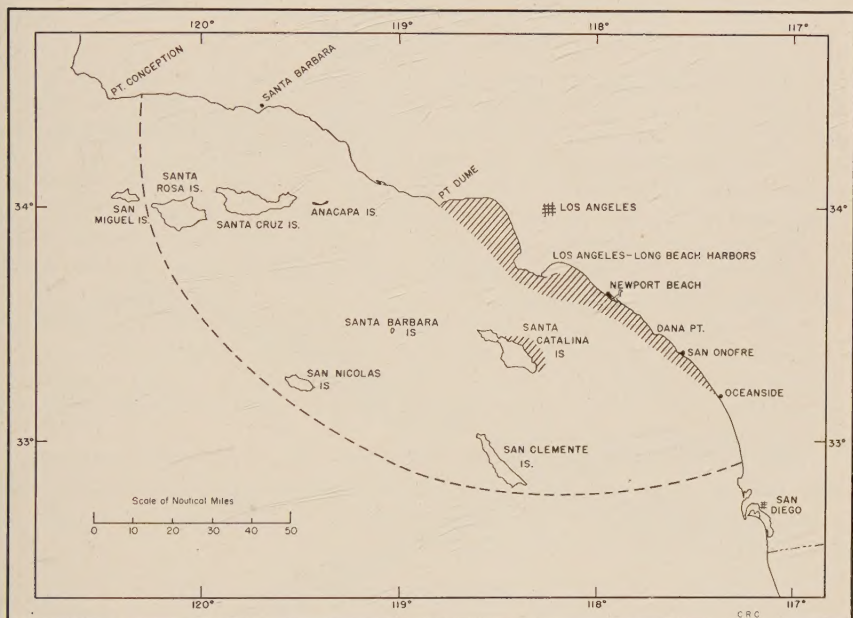


FIGURE 2. The coast of Southern California showing the area fished by the Los Angeles-Newport Beach mackerel fleet. Purse seiners exploit the area inside the broken line. Scoop boats operate chiefly in the shaded area.

At the present time (1948), there is no regular mackerel fishery in Central California. Until about 1941, a small hook-and-line fleet operated in Monterey Bay, supplying the fresh fish markets. The sardine fleet, which takes mackerel incidentally, operates between Pt. Reyes (30 miles northwest of San Francisco) and Pt. Buchon, about 100 miles south of Monterey. The San Francisco fleet fishes from north of Pt. Reyes to Monterey Bay.

Purpose and Scope of the Tagging Program

With the tremendous increase in the commercial importance of mackerel, the California Division of Fish and Game instituted a research program designed to provide sufficient knowledge of the species to permit its proper management. Of basic importance was an understanding of the movements of the fish—whether the Southern California fishery was exploiting one or more of several independent populations existing throughout the range or whether and to what degree fish from other areas contributed to the local catch. The tagging program was devised

originally in 1935 with this question in mind. It later seemed possible that tag returns might be used in studies of abundance and an intensified program was pursued in 1940 and 1941. With the outbreak of war, field work was greatly curtailed, though a few fish were tagged in the winter of 1942-43. Tags were collected through the 1946-47 season.

Three progress reports have been issued (Fry 1937b, 1941; Fry and Roedel 1939). These papers give more detailed information as to fishing methods and tagging techniques than is contained in the present publication, which does summarize the more pertinent data.

CONCLUSIONS

The tagging program demonstrated that mackerel from as far north as Oregon and as far south as the central portion of Lower California eventually entered the Southern California fishery. There was no evidence of a cyclic movement, although tagging in Lower California was not so conducted as to show such movement. There were indications of gradual dispersion over a period of years from the point of release. No fish were tagged south of central Lower California. There were few returned from this region and it seems probable that mackerel from farther south contribute little to the fishery.

Attempts to measure abundance through tag returns were not successful. The fundamental causes of failure were apparently incomplete dispersion and migration. The lack of sufficiently accurate measures of mortality caused by tagging and of tag loss due to inefficient recovery means were contributory.

Opercular tags, used initially, did not provide a permanent mark and proved useful only in tracing short-term movements in limited areas. Internal "belly" tags gave an enduring mark and were used on the great majority of tagged fish.

TECHNIQUES

Tags

Two types of tags were used. Initially, all fish were marked with strap opercular tags made of nickel. When clamped those tags measured about 3 mm. by 17 mm. Internal (belly) tags devised for the sardine tagging program were later adopted for use on mackerel. This type, made of nickel-plated steel, was available in two sizes. The larger, measuring 19 x 4 x 0.7 mm., proved most satisfactory, though the smaller, measuring 12.7 x 3.2 x 0.6 mm., was utilized on a few occasions when the catch consisted of unusually small fish. Both opercular and internal tags bore a serial number on the face and the inscription "CF&G" or "CALIF" on the reverse (Fig. 3).

Tagging Methods

Catching the Fish

Mackerel have been tagged on vessels ranging from 16 to 100 feet in length. A 29-foot salmon troller turned out to be the smallest on which profitable operations were possible. While it was adequate for small-scale tagging, a larger vessel equipped with a bait tank was found essential when large numbers of fish were to be handled. Though boats of 40 to 50 feet were satisfactory, the Division of Fish and Game research vessel

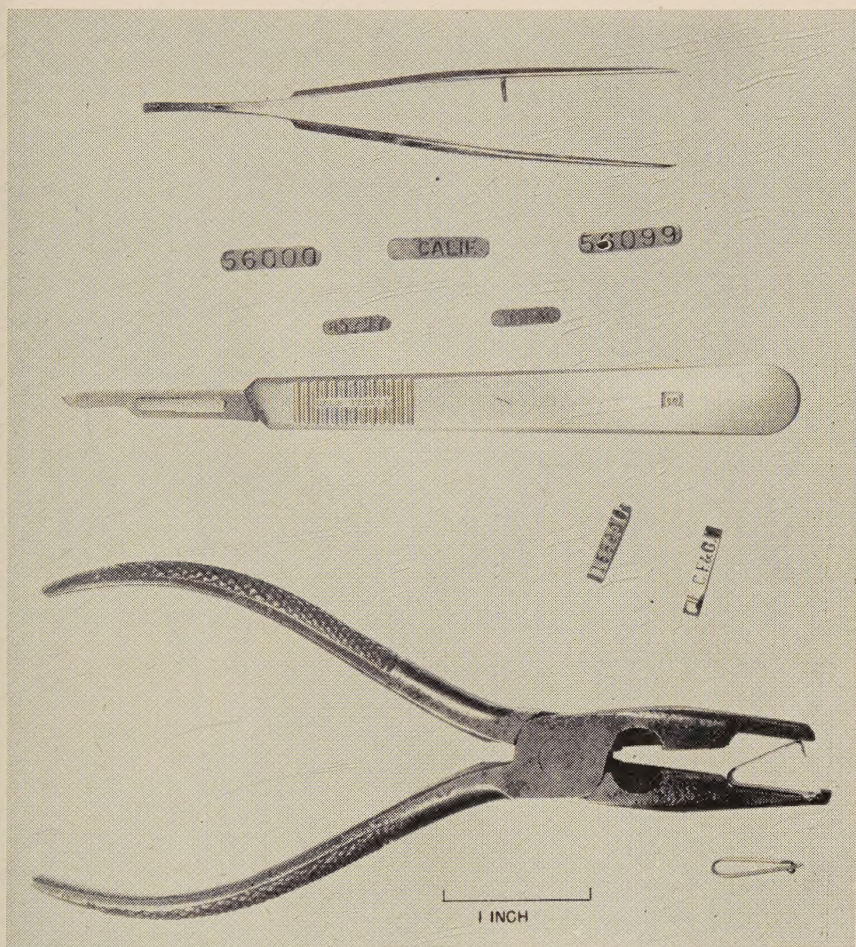


FIGURE 3. Tags and tagging tools. From top to bottom: forceps for inserting internal tags, internal tags, scalpel for making incision, opercular tags, pliers for crimping opercular tags. Photo by Al Johns for Vernon M. Haden, San Pedro.

N. B. Scofield, which is 100 feet long and is equipped with three large bait wells, proved ideal. Over 2,000 fish have been caught and tagged in one day on the *N. B. Scofield*; about half this number was the maximum on a smaller boat.

When working on boats with small bait tanks, the fish were usually held in an impounding net. The tank was of value when fishing was poor and frequent changes of location were necessary. On larger boats with tanks capable of holding several hundred fish, the impounding net was seldom necessary and on the *N. B. Scofield* was never used.

The commercial fishing method of scooping (Fig. 4) was employed for making the catch whenever possible. The scoop is a long-handled dip net with a deep bag hung on a spring steel hoop about 28 inches in diameter. The fish are first schooled about the boat by throwing out a

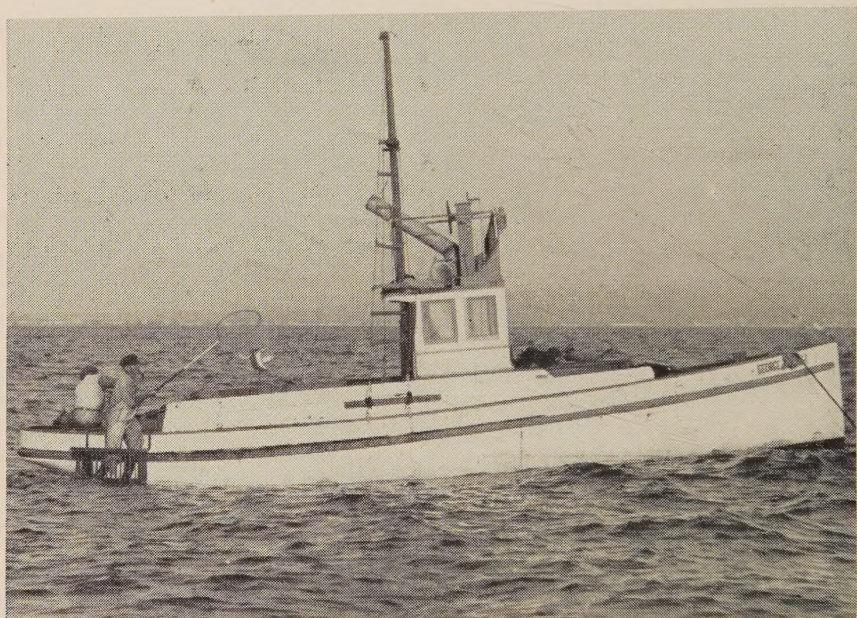


FIGURE 4. Commercial fishermen scooping mackerel. Photograph by D. H. Fry, Jr.

soupy mixture of ground bait and water. As the fish become excited they rush at each handful of bait as it enters the water, then follow it as it drifts away, only to come rushing back again as another handful is thrown overboard. Soon a regular pattern of movement develops and the fisherman puts his dipnet into the cloud of bait just as the fish enter it from the opposite side. The fish enter the net without seeing it and are lifted aboard. A good fisherman keeps up a regular cadence of throw, dip and lift, and the fish come aboard at an astonishing rate. Twenty per dip is not exceptional.

Ordinary bamboo poles and barbless hooks were utilized when the mackerel would not concentrate in large enough numbers to make scooping practicable. The hooks were feathered or baited depending upon the activity of the school. At times and particularly in Monterey Bay the fish will not school thickly at the surface. The catch then could be made only with baited hand lines.

In California waters, locating schools was generally a matter of simply fishing the grounds currently being worked by the commercial fleet. Off Lower California, where fishing operations are confined to the extreme northern section, schools were often found only after many days of scouting.

Tag Application

Tagging required a team of three men with assistance from a fourth when a large number of fish were to be marked. One man, wearing moderately heavy woolen or cotton gloves, held and measured the fish and dropped it overboard after the tag was applied. The second man applied the tag while the third recorded length and tag number. The

fourth man dipped fish from the bait tank or hoopounding net and passed them to the tagging table; he could readily supply fish for two teams when conditions warranted their operation (Fig. 5).



FIGURE 5. Marking mackerel with internal tags aboard the research vessel *N. B. Scofield*. The fish are held in the bait well from which they are lifted to the tagging table in a dip net. In this picture, the tagger (left) is making the incision in the body wall. Recording sheet and tag board are seen in the foreground. Photograph by C. R. Clothier.

Teams of two have functioned but tagging is slow. Here one man dipped and measured while the other tagged and recorded. A three-man crew, with one person dipping and recording was satisfactory for lots of up to several hundred fish.

Speed of tagging varied with weather conditions and working space on the boat. Experienced men in a team of four frequently marked 100 fish in 20 to 25 minutes under favorable circumstances. Work in the field was greatly facilitated by preparing record sheets and arranging the tags in consecutive order before each trip. The tags were inserted in boards drilled to hold lots of 100; 20 to 30 boards in turn were fitted into carrying cases which also contained a compartment for tagging equipment (Fig. 6).



FIGURE 6. A tag box. Each tray was filled in advance and a recording sheet attached to it. The compartments at the bottom held tagging equipment, extra tags and miscellaneous small gear. Tags were delivered by the manufacturer in the envelopes shown in the lower left corner. Each envelope held 100 tags numbered consecutively. Photograph by Vernon M. Haden, San Pedro.

A suitable tagging technique was developed only after much trial and error in the field. Good results were usually obtained when the fish were not crowded or frightened while in the bait tank, when handling was minimized and when the tag was applied with speed and precision. Capturing the fish held in a bait tank required skill on the part of the person dipping. A sudden movement of the dip net would panic the fish and would frequently result in individuals injuring themselves by dashing against the sides of the tank. When the tank was large enough, it was found best to confine a few fish at a time in a flag net (Fig. 7) which could be operated without frightening the impounded fish. Fish held in the flag net were usually quiet and could be caught with ease in the dip net.



FIGURE 7. Mackerel confined in a flag net to facilitate dipping. The great majority of the fish remain in the bait well below the net. Photograph by C. R. Clothier.

In following an ideal routine, the measurer seized the fish in the dip net with both hands and placed it on the measuring board belly up. As mackerel are both active and strong, his grip had to be rather firm to prevent escape. At the same time, he had to be careful not to exert so much pressure as to cause injury. Gloves, especially woolen gloves, made it much easier to prevent slippage without undue pressure, and in addition protected the hands from the mackerel's needle-sharp anal spines. With the fish in position, the measurer noted its length and then lifted the opercle if an external tag was to be applied. The tagger, using the pliers shown in Figure 3, then clinched the tag into place (Fig. 8) after

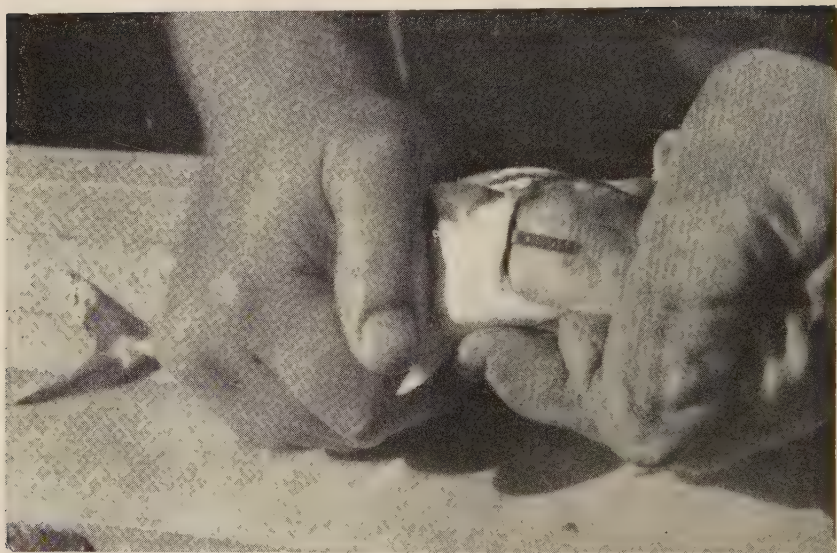


FIGURE 8. Opercular mackerel tag in place. Photograph by D. H. Fry, Jr.

which the measurer dropped the fish overboard. When applying internal tags, the measurer held the fish steady on the board. The tagger first made an incision in the body wall on the side of the fish and toward the posterior end of the body cavity, using a scalpel with replaceable blades (Fig. 3). The length of the incision when properly made was the same as the width of the blade and slightly less than the width of the large tags. The tagger had to guard against slashing a wide incision in the body wall and against cutting so deeply as to pierce the gut. The latter danger was especially great when the fish were full of food. It was found best to hold gorged fish for an hour or so before tagging. After making the incision the tag was pushed into the body cavity so that it would lie between the gut and the body wall. The tagger partially inserted it with his fingers and completed the operation with a pair of forceps. Before withdrawing the forceps, he gave the tag a quarter twist as a guard against its working out through the incision.

Measurements were taken to the nearest half centimeter but proved accurate only to one centimeter. All lengths were taken to the fork of the tail. The rule was inlaid on the inclined face of the board; the measurement was normally made just before the tag was applied.

Means of Recovery

The earliest tagging was done with opercular tags. These were used with the expectation that they would readily be noted by sport and commercial fishermen and a reward was offered for their return. Fishermen did turn in a large number which gave information on movements within Southern California waters over short time intervals, but it developed that these tags worked free within a relatively limited period. These tags invariably had a sharp wire edge when delivered. At first they were applied as received, but definite evidence was soon obtained that they worked free extremely rapidly. A tumbling drum was

then devised to smooth the tags. This worked most successfully. The drum, 9 inches in diameter and 24 inches in length, was ridged longitudinally and lined with fine emery cloth. The ridges were made by nailing 16 strips of three-quarter inch half round pine on the inside. When it was loaded with about five thousand tags and revolved at 55 r.p.m., the tags were in excellent condition after four to eight hours. The smoothed tags stayed in place far better but still did not provide a permanent mark. Of the 14,053 fish so tagged in the entire program, only 19 were recovered more than one year from the date of release. Fourteen of these were retaken within 18 months, four between 18 and 24 months and one after two years and four months.

Opercular tags were meantime being recovered on electro-magnets installed in cannery reduction plants as part of the sardine tagging program (Fry 1937a). The number of these recoveries indicated that the tags were not being seen and were not serving the purpose for which they were designed: observation by the fishermen who could then give detailed information as to the time and place of capture. Because opercular tags did not prove to be permanent and because they were not being observed, emphasis was shifted to internal tags in 1938. This type was not without its disadvantages. Recoveries by individual fishermen were virtually precluded. Since there was a considerable lag between capture of the fish and recovery of tags on magnets, the exact date and place of catch could not be determined and the returns were useless for tracing movements within the fishing area. For tracing inter-area movements and for studies involving returns over a period of years, the internal tag proved markedly superior because of its permanence. Recoveries in the fifth year were not unusual and one was returned seven years and eleven months after release.

Attempts were made to determine the approximate location of catch for many of the magnet recoveries. This was done with some apparent degree of success with returns at canneries whose boats fished consistently in one area for a considerable length of time. That condition rarely held true, and as more knowledge was obtained as to the lag between delivery of a load and the time of recovery of tags on the magnets, it was found that the chances of error were great enough to invalidate results. Tests carried on in conjunction with the sardine program (Clark and Janssen 1945b) indicated that at Los Angeles Harbor 78-79 percent of the tags were recovered within five days after entering the reduction plant and 94-95 percent within ten days. The remainder appeared as much as 200 or more days later with about 1 percent not being recovered until the following season. Therefore, magnet returns must be regarded only as having originated in the fishing area of the port concerned probably from catches made within ten days.

There are no reduction plants at Newport Beach, but numbers of tags were found there during canning operations and part of the Newport offal was shipped to Los Angeles Harbor plants for processing. Los Angeles Harbor magnet recoveries thus included some tags from fish taken by the Newport fleet. The two ports are considered as a unit in this paper both because of this factor and because the Los Angeles fleet covers the entire area exploited by Newport Beach fishermen.

CORRECTION FACTORS**Failure to Recover Tags****Measure of Loss Based on Magnet Efficiency**

There were many possible sources of tag loss from the moment a marked fish entered a cannery until the metal scrap accumulated on the magnet was searched. Tags might become lodged in the canneries proper, or in the reduction plants before reaching the magnets. The magnets were not equally efficient and received varying degrees of care from plant personnel. Some tags were undoubtedly overlooked by the person examining the scrap. In addition, several canneries which did not have reduction plants sent the offal to outside firms at which there were no facilities for tag recovery. A measure of these losses among internal tags was essential if the data were to be used for other than a check on the movement of tagged individuals.

To determine the theoretical number of tags which would have been returned if complete recovery had been accomplished thus required adjusting actual returns both for loss within magnet-equipped plants and for the proportion of the catch not passing over magnets. One part of the sardine tagging program involved measuring the loss of tags due to ineffectiveness of magnets and failure to find tags in the accumulated scrap metal (Clark and Janssen, 1945b). This was accomplished by tagging fish as they entered the reduction plant; any loss in the cannery proper consequently remained uncorrected. Mackerel tag returns were first weighted by the seasonal efficiency index of the plant concerned as determined from these tests, the index being the percentage of test tags recovered

$$\left(\text{recoveries at 100\% magnet efficiency} = \frac{\text{actual recoveries} \times 100}{\text{percent of test tags recovered}} \right).$$

The total number of recoveries at 100 percent magnet efficiency in a given month was then corrected for the proportion of the catch not passing over magnets

$$\left(\text{fully weighted recoveries} = \frac{\text{recoveries at 100 percent efficiency} \times 100}{\text{percent of catch passing over magnets}} \right).$$

These correction factors (Table 1) showed a wide variation in magnet efficiency from plant to plant and season to season. The percentage of the catch passing over magnets fluctuated as well. This was due in part to variations in the size of the Newport Beach fishery.

In some plants without magnets, tags were found by the cannery employees. Rewards were paid for these tags. In one plant with a magnet workers found a place where tags lodged before reaching the magnet. We soon stopped paying rewards for such tags because of the possibility that they would later be caught on the magnet. There was no evidence that the magnets were ever robbed for the sake of tag rewards. There were more test tags (distinguishable only by serial number) in the plants than there were "live tags" and no one ever attempted to turn in a test tag.

All recoveries made by cannery personnel have been disregarded in analyzing weighted returns. In theory, weighted magnet recoveries accounted for all the tags which were landed and any attempt to use

TABLE 1
CORRECTION FACTORS USED IN WEIGHTING MACKEREL TAG RETURNS

A. Percentage of Test Tags Recovered on Magnets in Reduction Plants of Mackerel Canneries in the Los Angeles-Long Beach Harbor Area. Data From Tests Made in Conjunction With the Sardine Tagging Program

Plant	Percentage of test tags recovered								
	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1944-45	1945-46
A	40.0	37.9		40.5	36.5	37.6	79.0	53.8	74.9
B	82.5	33.3		71.0	83.6	74.0	88.0	85.4	78.5
C	85.0	87.6	56.6	70.3	76.0	67.2	77.5	88.9	97.0
D	82.5	40.5	96.6	95.4	85.3	82.0	52.5	49.5	88.7
E	52.5	83.0	94.5	92.8	84.8	94.8	95.0	91.0	99.0
F	75.0	79.1	76.6	93.5	91.5	76.4	75.5	63.5	81.5
G	65.0		55.0	59.8	80.7	72.4	92.7	43.5	80.0
H	25.0	42.5	65.6	72.1	77.0	58.0	67.0	60.0	67.3
I	40.0			71.8	64.0	80.8	48.7	47.3	62.7
J		70.0	90.2	81.6	62.4	61.8	51.3	55.8	76.9
K					56.8	76.8	76.0	68.5	40.8
L					74.0	78.5	76.0	70.5	73.0
M	95.0		90.5	96.5	77.0	98.0	98.0	94.7	80.4
N					89.2	41.6	90.0	86.9	46.3
O					72.7	90.0	82.0	52.7	83.9
P								72.0	67.5

B. Percentage of Cannery Mackerel Catch at Los Angeles-Long Beach Harbors and at Newport Beach Passing Over Magnets

Month	Percentage of catch passing over magnets								
	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44	1944-45	1945-46
June		73.8	43.5	*	*	*	*	100.0	*
July	Not	62.3	68.1	64.3	56.8	*	100.0	100.0	*
August	calcu-	59.5	64.4	67.7	70.6	*	100.0	91.8	89.5
Sept.	lated	59.7	63.5	64.5	68.3	80.1	86.8	83.7	77.5
Oct.		43.1	46.1	61.6	61.8	73.0	67.1	74.1	72.3
Nov.		23.7	58.4	59.9	68.9	81.3	80.6	71.8	67.4
Dec.		36.9	58.8	63.3	87.4	78.7	70.0	76.7	78.5
Jan.	60.9	39.7	61.8	65.8	98.0	52.2	70.9	73.9	88.1
Feb.	24.5	*	63.4	58.5	92.7	65.5	85.0	97.4	100.0
March	* 37.3	61.6	67.8	82.9	99.6	42.7	100.0	0.0	100.0

* No cannery mackerel landings.

other tags complicated the picture and contributed nothing. Nonmagnet recoveries were too sporadic to use; the efficiency of recovery could not be properly tested, and the numbers were too small to be significant.

In some preliminary work, weighting was done on the basis of the monthly efficiency index of each plant. It was decided, however, that the complication introduced by the time lag between capture of the fish and recovery of the tag coupled with the fluctuation in observed magnet efficiencies over short time periods made the seasonal value a more reliable measure than the monthly. It can be argued that the general efficiency of the port over a season is a better measure than the efficiencies of the individual plants. However, the mackerel catch is not distributed evenly among plants. A few handle large quantities while others process only an occasional load. Under these circumstances, the individual plant index was adopted as the best measure.

By the close of the 1945-46 season, it was apparent that only scattered returns could be expected in the future. As a result, tests of magnet

efficiency were not made in 1946-47, though the magnet scrap was searched for tags until the end of that season. No attempt was made to recover tags in the following seasons.

Tag Loss in Canning Lines

The correction factors derived from tests of magnet efficiency did not account for any loss which might have been sustained in the canneries proper before the offal reached the reduction pits. The final analysis of sardine tag returns indicated that the recovery rate was as high from sardines used for canning as from those used for whole reduction. It did not necessarily follow that cannery loss was negligible for mackerel, and the discovery of a number of tags entrapped in a cannery sump showed that the error introduced by correcting only for reduction plant loss might be appreciable. Tests were designed to measure the extent of loss along the canning lines and a few experiments of two types were carried out in the fall of 1940. The first involved insertion of tags into fish as they entered the cannery rather than when they reached the reduction pit. This means was not satisfactory, for the tags lay free in the body cavity whereas they became encysted in the great majority of living fish. Consequently, there was a greater chance of a test tag becoming lost along the canning line. In the second type, marked survivors¹ of holding experiments designed to measure tagging mortality were placed in the canning lines. While these tests duplicated the conditions encountered by tagged fish in the commercial catch, the number of individuals available was very small. In any event, it did not prove possible to carry out more than preliminary experiments as the plant operators objected on the grounds that there was too much danger of tags inadvertently entering the pack. (It is interesting in this connection to note that the operators' fear of suit in the event of a purchaser finding a tag in the pack was confined to tags introduced into fish already in their possession. A tag from a fish marked in the sea was considered an event beyond their control and hence not subject to legal action. We did receive one tag found in a can by a consumer.)

In all, six tests involving the insertion of tags into dead fish and seven involving the survivors of holding experiments were made in conjunction with the usual tests of magnet efficiency (Table 2). On the six occasions when all three tests were made simultaneously, 77 percent of the tags were recovered from the 287 inserted in the usual manner into fish in the reduction pits. Tags from 62.1 percent of the 182 survivors of the holding experiments were recovered, but only 51.8 percent of the 284 tags inserted into dead fish. These experiments were run at two plants, each a large producer of canned mackerel. At one plant, returns from holding experiment fish were nearly as good as returns from the reduction plant tests but the disparity at the second plant was far greater. The seventh experiment, involving only the standard test and holding experiment fish was made at a third plant and gave roughly equal returns from both tests. Variations in the physical layouts of the plants and in the care with which the fish were cleaned undoubtedly determined the amount of tag loss during canning.

¹ To determine whether a fish bore a tag, each supposedly tagged fish was passed over a bar magnet about 8 inches long. This magnet was floated on a circular disc of thin wood. The presence of a tag would rotate this compass-like device as the fish was moved past one end of the magnet. The movement was of large magnitude (30-50°) hence was unmistakable.

TABLE 2
RESULTS OF TESTS DESIGNED TO MEASURE TAG LOSS IN CANNERIES ¹

	1 Standard test of magnet efficiency			2 Fish from holding experiments introduced into canning lines			3 Fish tagged in canneries		
	Number of tags	Recoveries	Percentage recovered	Number of tags	Recoveries	Percentage recovered	Number of tags	Recoveries	Percentage recovered
Plant A	143	123	86.0	91	53	58.2	141	70	49.6
Plant B	144	98	68.1	91	60	65.9	143	77	53.8
Total	287	221	77.0	182	113	62.1	284	147	51.8
Standard error			±2.5			±3.6			±2.8
Weighted percentage			100.0			80.6			67.3
Plant C	49	27	55.1	32	18	56.2			
Total	336	248	73.8	214	131	61.2			
Standard error			±2.4			±3.3			
Weighted percentage			100.0			82.9			

¹ The standard test (1) involved tagging fish in the reduction pit. The other two involved placing tagged fish in the cannery proper. Those from the holding experiments (2) had been tagged while alive and confined for several weeks; the others (3) were tagged in the cannery. Test 2 most nearly duplicates conditions encountered by tagged fish entering the catch.

A total of 73.8 percent of the standard test tags and 61.2 percent of the holding experiment fish were recovered from the seven experiments. The 12.6 percent difference between the two recovery rates is significant, being slightly more than three times the standard error of 4 percent $\left(\sqrt{pq \left(\frac{1}{N_1} + \frac{1}{N_2} \right)} \right)$. This reflects circumstances in Plant A

rather than a general condition in the three concerned; it is probable that the standard weighting procedure appreciably underestimated tag returns in the one case, at least during the three months covered by the tests. There is no way of determining conditions prevalent in other plants handling mackerel, or, for that matter, of knowing whether the results obtained would be typical over a long time period at the plants tested.

Double Tagging as a Measure of Tag Loss

In 1940 and 1941, over 1,600 fish were marked with both opercular and internal tags. It was felt that magnet returns from these double-tagged individuals would give a measure of tag loss independent of that determined from the standard tests. In deriving this measure, the loss of one tag was assumed to be entirely independent of the loss of the other, both in the ocean and in the cannery, except for natural and tagging mortality. From the total number of double-tagged fish entering the canneries at which there were facilities for tag recovery, we recovered only internal tags from some individuals, only opercular tags from others, and both from still others. Then, when

a = The total number of internal tags recovered on magnets

b = The total number of opercular tags recovered on magnets

c = The total number of fish from which both tags were recovered, and

N = The number of fish initially double-tagged entering the catch of magnet-equipped plants

N can be determined from the formula $\left(\frac{a}{N} \right) \left(\frac{b}{N} \right) = \frac{c}{N}$.

The percentage of either type of tag recovered is then readily obtained and magnet returns from single-tagged fish can be weighted proportionately. Applying the method to returns in 1940-41 from double-tagged fish released in the same season, $a=84$, $b=73$ and $c=36$. Solving, $N=170.3$. The chances of recovering an internal tag become $84 \times 100 \div 170.3$ or 49.3 percent and of recovering an opercular tag, 42.9 percent. Returns in 1941-42 from double-tagged fish released in that season show the chances of recovering internal tags to be 33.8 percent and of recovering opercular tags, 31.7 percent ($a=79$, $b=74$, $c=25$).

The differences between the number of fish from which internals only, from which opercular tags only or from which both tags were recovered in the two years are not significant when measured by the chi-square test ($P=.15$). Consequently, the difference between the chance of recovery calculated for each season cannot be regarded as significant, and the two years' data could justifiably be combined.

The factors obtained by using this method are not directly comparable with those obtained from the standard reduction plant tests, which account only for loss of actual tags within the plants. The double-tagging method measures as well tag loss in the ocean as a result of shedding and loss in the cannery proper. Tests designed to measure death as a result of tagging showed that approximately 5 percent of the fish surviving internal marking shed their tags (Table 3). But bearing this in mind, the recovery rate as determined from double tag returns was still far below that indicated by the tests of magnet efficiency (Table 1). In 1940-41, there were 11 plant indices ranging from 40.5 percent to 96.5 percent with an average recovery rate of 76.8 percent, as compared with the recovery rate of 49.3 percent indicated by double tag returns. In 1941-42, the average of the 15 indices was 74.1 percent while the rate derived from double tag returns was 33.8 percent.

Evaluation of the Measures of Loss

The disparity between recovery rates derived from the standard reduction plant tests and the double-tagging experiments was so great that the accuracy of the former was subject to question insofar as weighting mackerel tags was concerned. Undoubtedly, it underestimated actual recaptures to some degree as evidenced by the results of the canning line tests. The results of the canning line tests did more nearly approach the values obtained from the reduction plant tests, and it seems likely that the double-tagging method overestimated tag loss.

Both the double tagging and the canning line tests were based on insufficient numbers to give really reliable results. Further, the double-tagging experiments were carried on during only two seasons and the canning line tests in part of one. Considering all the factors involved, the standard reduction plant measures remained the most reliable means at hand of adjusting for tag loss, and all corrections of actual recoveries were based upon them. They must, however, be regarded as giving a minimal estimate of actual recaptures, the effects of which are discussed in the section "Studies of Abundance."

Tagging Mortality

Holding Experiments

The use of tag returns in studies of abundance required a measure of the proportion of internally tagged fish which survived the tagging operation and retained the tag. (The term "tagging mortality" as used herein includes both death resulting from tagging whether or not the tag was shed and shedding of tags by fish which survived.) Shortages of personnel and equipment precluded exhaustive tests, but in the summer and fall of 1940 a live box used for the same purpose in sardine investigations was available and a series of five tests was made. The box, consisting of four compartments each approximately 6x6x4 feet, is described in detail by Janssen and Aplin (1945).

Fish used in the tests were caught in the immediate vicinity of Newport Beach, where the box was moored, carried to the box in bait tanks and tagged in the usual manner. In three of the tests, approximately half of the fish were tagged immediately on arrival at the live box and the rest held as controls. The other two tests involved tagging the controls on conclusion of the initial experiments. These latter are referred to as "conditioned fish"; the former as "unconditioned fish."

Holding a fish as large and active as a mackerel in the live boxes had a pronounced physical effect in the great majority of cases. The boxes were not large enough to permit the fish to circle freely, and they frequently bumped against the sides as a result. Fish examined on completion of the experiments usually exhibited some degree of swelling and redness about the jaws and snout. In many cases, the entire head was swollen, sometimes to a very marked degree. Fraying of the caudal and reddening of other fins was not uncommon and ulcerous sores were noted on a few individuals.

In one test, some unknown factor wiped out a large proportion of both tagged fish and controls. In two others, the fish soon became very slimy, a condition which persisted throughout the experiment. Such marked effects of holding may well have obscured the true effect of the tagging operation.

The live box was visited daily at the start of each experiment and at two or three day intervals thereafter. The fish were fed live anchovies when they were available and ground sardines at other times.

The position and degree of encystment of tags was checked in fish dying during the experiments as well as in a portion of the survivors. In the great majority of cases, the tags were attached in some degree by the end of two weeks. They lodged most often in the gonads, though many were attached to the stomach wall or to the mesenteries. Occasionally, a tag was found free in the body cavity at the end of an experiment. Deaths occurred most frequently in the first 10 days, dropped off in the next 10, and were infrequent thereafter.

Average minimum and average maximum tagging mortalities have been calculated from the experimental data. The measure of maximum mortality represents the percentage of unconditioned fish dying or shedding their tags, and includes the loss due to catching, transporting, tagging, and confinement. Because the latter effect is included, the value obtained is presumed higher than would ever be the case in the field.

The measure of minimum mortality is based on the assumption that the only difference in treatment between tagged fish and their controls is

the insertion of the tag. For controlled tests, minimum mortality is represented by the value of m in the expression $m + c - mc/100 = L$, where c is the percentage of controls which died and L the percentage of tagged fish either dying or shedding their tags. In the single test of conditioned fish run without controls, it is the percentage dying or shedding. Minimum mortality, then, accounts only for deaths caused by the actual tagging operation. As it eliminates the effect of capture, it is a lower value than would theoretically be anticipated in the field, although it could be argued that deaths from all causes would increase as a result of confinement, and that the effect of tagging on captive fish was much more severe than on fish which were released immediately after tagging.

TABLE 3
RESULTS OF HOLDING EXPERIMENTS DESIGNED TO MEASURE MORTALITY DUE TO TAGGING

Lot	Tagged fish					Controls		Minimum mortality, m
	Number	Percentage living with tag	Percentage living without tag	Percentage dying	Maximum mortality, L	Number	Percentage dying	
"Unconditioned"								
1-----	63	57.2	11.1	31.7	42.8	42	35.7	11.0
2-----	135	42.2	5.9	51.9	57.8	109	22.9	45.3
3-----	147	28.6	4.1	67.3	71.4	144	52.8	39.4
Average maximum mortality-----					57.3			
"Conditioned"								
4-----	54	96.3		3.7	3.7	54	1.9	1.8
5-----	66	84.9	3.0	12.1	15.1			15.1
Average shed-----			4.8					
Average minimum mortality-----								22.52

Results are shown in Table 3. The average minimum mortality was found to be 23 percent; the average maximum based on the three tests involving unconditioned fish, 57 percent. These results point toward an average mortality of about 40 percent: the mean of average maximum and minimum mortalities. The rates include tags shed by about 5 percent of the survivors. Both minimum mortality and percentage shed were higher among unconditioned fish. The rather large difference in results between the tests cannot be attributed to differences in tagging technique as only experienced men handled the fish.

It is believed that the calculated minimum is the best measure of mortality among carefully tagged fish where confinement and transportation were eliminated or minimized. Such fish were subject to but little more handling than those in the conditioned tests. The measure of minimum mortality among conditioned fish, which had perforce to be recaptured in the live boxes prior to tagging, actually includes more handling than does the same measure for unconditioned fish, in which all effect of handling other than tag insertion is deducted. Yet the conditioned fish suffered a lower mortality than the average minimum for unconditioned. This result may stem from the pronounced initial effects of holding. In

any event, the results can be regarded only as indicative since but 465 tagged fish were included in the tests.

There were indications that the effect of holding the fish caused a higher death rate in the larger sizes. Selection of controls was theoretically random insofar as size was concerned. The usual practice was to tag several fish and then place an equal number in the control compartment. Yet the length frequency of the controls when they were later tagged was appreciably lower than that of the unconditioned fish. Comparison of the frequencies using the chi-square test gives a P value of .01, significant if the controls and tagged fish were initially of the same size distribution. In experiments one and two, deaths were apparently higher among the large fish tagged. No direct measure can be made, as neither the length of fish dying without tags nor the length of the fish living without tags is known.

Cumulative Mortality

When a day's tagging involved more than a few hundred fish, it was thought that mortality might be greater among those last released as a result both of fatigue on the part of the tagging team and the lengthier confinement of the fish. A check of returns per 100 fish tagged showed that a decrease in returns toward the end of a tagging day did occur in scattered instances. In other cases, returns from the later hundreds exceeded those from the earlier while in most no trend was observed.

Differences Between Tagging Teams

With many persons of all degrees of experience acting as measurers and taggers, a differential mortality between teams was anticipated, but an examination of returns failed to show significant differences between experienced and inexperienced teams working simultaneously. Presumably the careful coaching received by inexperienced men tended to bring their work up to standard. In general a tagging team included no more than one inexperienced man.

Mortality Among Double-Tagged Fish

Another potential cause of higher mortality lay in double-tagging, as this process was necessarily slower and involved additional handling. Double-tagged fish were released on nineteen tagging days, nine in 1940 and ten in 1941. Excepting one day in 1940, both double and single (internally) tagged fish were released on each occasion. Magnet returns of internal tags from double-tagged fish were compared with magnet returns from single-tagged fish marked by the same tagging team (Table 4). On six of the eighteen days represented, percentage returns were higher from double-tagged fish. The results of chi-square tests indicated no significant differences between returns from these groups. The same was true for nine of the twelve tagging days where returns from double-tagged fish were less than returns from those single-tagged. P values ranged upward from 10 percent. Differences of borderline significance were indicated by returns from two of the remaining groups ($P = .04$ and $.05$) and a significant difference ($P = .015$) by returns from the third. These three lots were released in 1941. Despite the variations noted when the individual days were tested and the general lack of significant differences, the pooled data demonstrated some bias in

TABLE 4
MAGNET RETURNS AT LOS ANGELES HARBOR FROM DOUBLE AND SINGLE (INTERNALLY) TAGGED FISH MARKED ON THE SAME DAY BY THE SAME TAGGING CREW

Group	Fish marked with both internal and opercular tags					Fish marked with internal tags only			Value of P (from Chi-Square test of returns of internal tags)
	Magnet recoveries					Number tagged	Magnet recoveries	Percentage recovered	
	Opercular only	Internal only	Both	Total fish recovered	Total internals				
1940—	98	2	6	11	9	220	36	16.4	> .05
1-----	61	4	3	8	4	98	6	6.1	> .05
2-----	99	2	5	10	8	143	16	11.2	> .05
3-----	99	0	10	31	22	34	4	11.8	> .05
4-----	92	5	6	12	11	360	57	15.8	> .05
5-----	99	5	3	14	9	258	33	12.8	> .05
6-----	99	5	3	14	9	316	15	4.7	> .05
7-----	90	4	1	10	6	151	45	29.8	> .05
8-----	66	1	11	17	16				
Total-----	704	32	47	117	85	1,580	212	13.4	> .05
1941—	96	1	1	3	2	216	20	9.3	.04
1-----	59	6	3	11	5	139	21	15.1	> .05
2-----	96	2	0	2	0	427	22	5.1	> .05
3-----	98	9	18	31	22	555	96	17.2	> .05
4-----	99	12	10	26	14	22.4	58	19.3	> .05
5-----	100	6	5	14	8	301	45	15.0	> .05
6-----	39	4	1	5	1	300	37	20.4	.015
7-----	100	9	13	27	18	183	33	16.5	> .05
8-----	99	2	11	15	13	200	30	11.2	> .05
9-----	99	2	5	10	8	268	37	12.3	> .05
10-----									
Total-----	885	53	67	144	91	2,893	399	13.8	.008
Grand total-----	1,589	85	114	261	176	4,473	611	13.7	.01

favor of single-tagging. The 1940 lots did not show a significant difference (P about .40) but the 1941 lots and the experiment total did ($P = < .01$ and .01 respectively). This indicates that double-tagging in 1941 was not as successful as it was in 1940. Additional mortality caused by double-tagging was, however, apparently not a serious factor, and no allowance was made for it in weighting tag returns. Relatively few fish were marked with both tags, and any errors introduced by additional mortality among them are insignificant when the errors inherent in weighting and in measuring tagging mortality are taken into account.

RELEASES

From the inception of the program in July, 1935, to its end in March, 1943, a total of 76,038 mackerel were tagged. Of these, 12,426 were marked with opercular tags, 61,985 with internal tags, and 1,627 with both tags. Releases by year and area are summarized in Table 5.

TABLE 5
SUMMARY OF RELEASES BY REGION AND TYPE OF TAG

Year	Type of tag	Number tagged				
		Central California	Southern California	Northern Lower California	Central Lower California	Total
1935	Opercular	538	215		194	947
1936	Opercular	199	1,708		1,005	2,912
	Internal		212			212
	Total	199	1,920		1,005	3,124
1937	Opercular	2,344	1,101			3,445
	Internal	2,322	1,288	15		3,625
	Total	4,666	2,389	15		7,070
1938	Opercular		2,962		20	2,982
	Internal		3,407		27	3,434
	Total		6,369		47	6,416
1939	Opercular	19	2,018			2,037
	Internal	482	202		721	1,405
	Total	501	2,220		721	3,442
1940	Opercular		103			103
	Internal		6,738	3,937	982	11,657 ¹
	Both		742			742
	Total		7,583	3,937	982	12,502
1941	Internal	1,082	19,447	468	14,283	35,280
	Both		885			885
	Total	1,082	20,332	468	14,283	36,165
1942	Internal		1,175			1,175
1943	Internal		5,197			5,197
Grand Total	Opercular	3,100	8,107		1,219	12,426
	Internal	3,886	37,666	4,420	16,013	61,985
	Both		1,627			1,627
	Total	6,986	47,400	4,420	17,232	76,038

¹ An additional 11 fish were marked off the northern Oregon coast by the Fisheries Research Board of Canada in 1940.

Most of the work in 1935 and 1936 was experimental, and demonstrated the serious flaws in the opercular tags then in use. Both improved opercular and internal tags were used in the next three years. Tagging received no particular priority over other phases of mackerel investigations during this period though efforts were made to release fish over as wide an area as possible.

Under the intensified program carried on in 1940 and 1941, plans called for the release of large numbers of internally-tagged fish throughout the year at a number of points in Southern California and Lower California with supplementary tagging in Central California. Personnel shortages and other demands on suitable vessels precluded fulfillment of this basic objective. In Southern California, tagging was concentrated largely in the areas exploited by the scoop fleet and during the fishing season. Very few fish were released either north of Santa Monica Bay or in the San Diego area, while only one sizeable lot was tagged in the off season, this at Santa Catalina Island (Fig. 2).

Our operations in Lower California were all accomplished during the Southern California fishing season, almost exclusively in the months of February and October. The original plans provided for tagging as far south as Magdalena Bay, but the southernmost point at which fish were found in quantity proved to be San Roque Bay, some 200 miles farther north. It was not possible to make any trips in the spring and summer, and that no fish could be tagged during the California period of scarcity is especially regrettable.

Tagging was successful in both the northern and central sections of the peninsula, over 20,000 internally-marked fish being released between October, 1939, and October, 1941. The great majority were tagged in the central section, which forms two general areas in itself: Sebastian Viscaino Bay, roughly half way down the peninsula, and the coast immediately south which embraces Thurloe and San Roque bays (Fig. 9).

Prior to 1939, 1,261 fish were released in Mexican waters as far south as Magdalena Bay. Virtually all of this tagging was effected in 1935 and 1936, using the opercular tags later found to be unsatisfactory. That there have been no recoveries may be attributed to their use.

Over 4,000 fish were released in Monterey Bay in the fall of 1937, about half being marked with internal tags. A lot of a few hundred was tagged in the fall of 1939 and another 1,000 in the fall of 1941, both with internal tags. Virtually all of the fish were released in the southern portion of the bay within a few miles of the city of Monterey. No other tagging of consequence was accomplished in Central California.

Through the courtesy of Dr. John L. Hart of the Fisheries Research Board of Canada, eleven mackerel were marked in 1940 off Tillamook Head, Oregon, in the course of sardine tagging. These are the only mackerel released north of Monterey Bay.

Nearly all of the fish marked were of commercial size at the time of release, ranging in length from 20 to 40 centimeters to the fork of the tail with a majority between 25 and 35 centimeters. One group of 1,000 younger fish, 15 to 20 centimeters in length, was tagged at Blanca Bay, Lower California.

In handling the data, the many tagging days on which internally-marked fish were released have been combined into tag lots, each lot representing releases in a given area over a limited period of time. Central

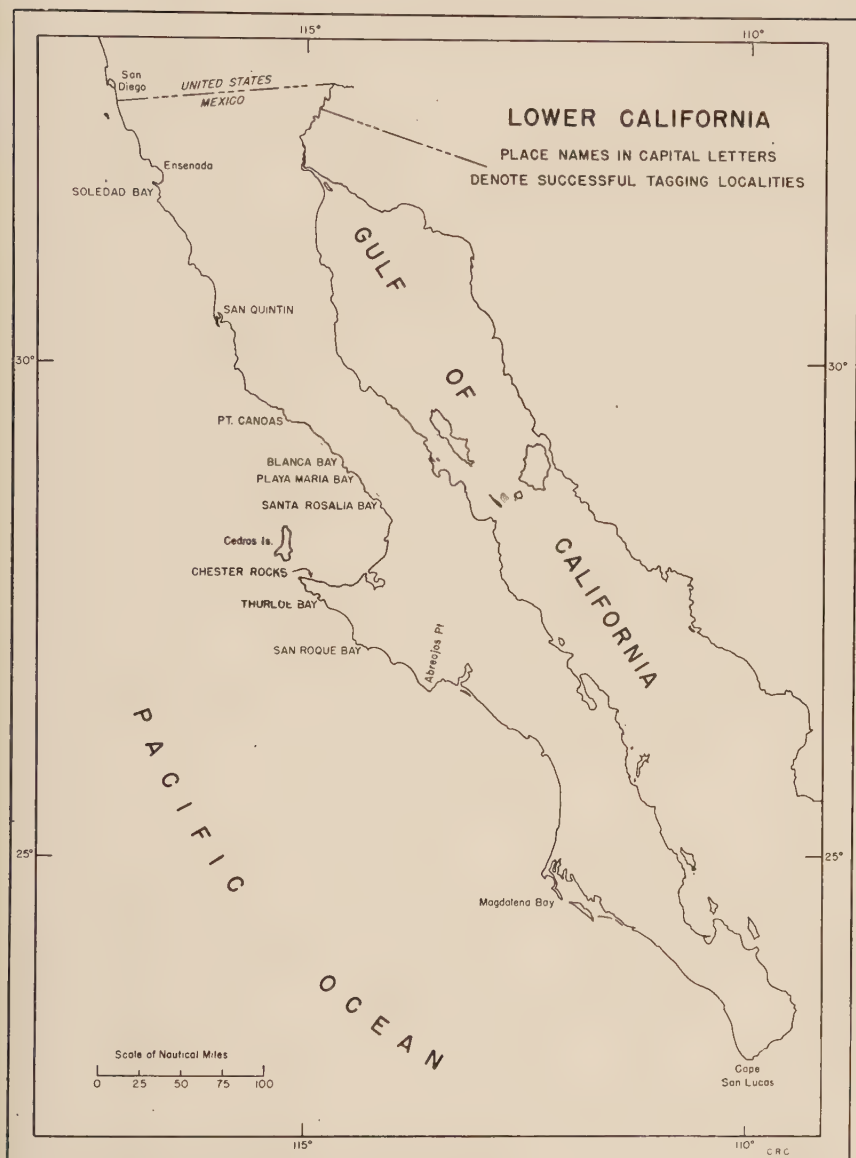


FIGURE 9

California releases are considered as three lots representing the fall tagging in 1937, 1939, and 1941. The Lower California lots form clear-cut units, as tagging was carried on at rather widely separated localities and the time spent working a given area never exceeded a few days.

A preliminary survey of the various groups of fish released in Southern California resulted in the elimination of a total of 1,762 of the 39,081 internally and double-tagged fish released from 1937 through 1943. The work done in 1936 was experimental in nature and 212 fish tagged that

year were not considered for this reason. A number of tagging days on which under 100 fish were released and from which there were either scattered or no returns were dropped when they could not logically be combined into a tag lot. A few tagging days involving greater numbers of tagged fish were eliminated when known adverse conditions resulted in abnormally high mortality and consequent failure to recover other than an occasional tag. Bad weather was usually the underlying cause of these failures. It never proved productive to tag when the fish were being battered in the bait tank, or when the tagging crew could not find secure footing or was plagued with seasickness.

The 19 tag lots (Table 6) finally adopted include 37,319 individuals and represent five geographical areas. The bulk of tagging was accomplished in three of these areas which correspond to the grounds most heavily exploited by the scoop fleet. These are Santa Catalina Island, Santa Monica Bay, and the Newport region, this including the mainland coast from San Pedro to San Onofre but centering in the vicinity of Newport Beach and Dana Point. The remaining two areas are outlying and are represented by single lots, one released at Santa Cruz Island and one off San Diego in 1941-42, the only season in which all five areas are represented.

Tagging was very successful in the three major areas in 1940-41, 1941-42, and 1942-43. Prior to the 1940-41 season, only two successful lots were released, one at Santa Catalina Island in 1937-38 and the other in Santa Monica Bay in 1939-40. Each of the 19 lots gave returns in season one (the first season after tagging; the fishing season during which a lot was released is termed season zero) while eleven reappeared in the catch at least through season three.

MIGRATIONS

Southerly Movements

From the Pacific Northwest

That mackerel from the northern part of the range reach Southern California waters is attested by the recovery at a Los Angeles harbor cannery of a tag from one of the 11 fish released off Tillamook Head, Oregon, just south of the mouth of the Columbia River. This fish was marked in August, 1940, and recaptured in January, 1943. We are indebted to the Fisheries Research Board of Canada for permission to publish this record.

From Central California

The magnitude of southerly movements is demonstrated most strikingly by returns from fish released in Central California (Table 7; Figure 10) where tagging was accomplished in five years, 1935, 1936, 1937, 1939, and 1941. There have been no recoveries from the 1935 group; this is attributed to imperfections later discovered in the opercular tags then in use. Returns from the remaining four years total 249, of which only 77 were recovered in Central California. There were 171 recoveries in Southern California and one at Ensenada, Mexico, the southernmost port at which there were facilities for tag recovery.

Internal tagging operations were concentrated in the fall months of 1937, 1939, and 1941. The bulk of the information available as to the

TABLE 6
THE SOUTHERN CALIFORNIA TAG LOTS SHOWING MAGNET RETURNS AT LOS ANGELES HARBOR THROUGH THE 1946-1947 SEASON

Releases			Magnet recoveries at Los Angeles harbor															
Time	Area ¹	Number	Season 0		Season 1		Season 2		Season 3		Season 4		Season 5		Total through 1945-46 season			
			Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted		
1937-38 season Dec. 37-Feb. 38	Santa Catalina	3,918	1937-38	238.6	67	263.4	73	180.5	19	40.3	6	9.4	1	2.0	213 ²	734.2		
			47															
1939-40 season May 1940	Santa Monica Bay	705	1939-40		25	52.8	11	23.0	1	2.5					37	78.3		
1940-41 season June-Aug. 1940 August 1940 October 1940 October 1940 October 1940 Dec. 40-Mar. 41 Mar.-May 1941	Newport	4,010	1940-41		37	72.3	6	13.4	2	4.3			1	1.3	533	1,057.1		
			487	965.8	37													
			38	87.1	5	10.0												
			123	259.7	10	20.6	3	6.1										
			634		2	4.2												
			513	56.2	2													
			28		222	423.3	26	50.6	6	10.8	1	2.7						
			5,864	1,115	2395.2	31	66.6	6	12.6	2	4.1	1	1.7					
3,772		156	286.1															
Season...	Southern California	15,093	1,791	3,764.0	432	816.5	66	136.7	14	27.7	3	6.8	3	5.2	2,309	4,756.9		
1941-42 season July 1941 July 1941 September 1941 September 1941 October 1941 October 1941 October 1941 October 1941 October 1941	Santa Catalina	510	1941-42		4	10.6	1	2.5							49	101.3		
			44	88.2	4													
			574	55.4	2	4.0												
			2,999	909.1	28	52.7	5	10.8	4	7.8	1	1.4						
			2,504		9	15.1	2	4.1	1	1.3	1	1.3						
			2,193	488.6	19	38.6	4	6.3	3	5.5	1	1.3						
			497	118.8	2	3.6												
			835	73.0	11	21.8			2	3.0								
1,119	87.6	17	31.5			1	1.5											
Season...	Southern California	11,231	1,235	2,524.0	92	177.9	12	23.7	11	19.1	3	4.0	1*		1,353	2,748.7		
1942-43 season Nov. 42-Jan. 43 February 1943 March 1943	Santa Catalina	2,474	1942-43		75	142.7	22	40.7	9	16.5	3*				212	500.9		
			106	301.0	15	28.6	5	10.5	1*									
			5	18.0	77	157.8	19	37.0	11	16.7	1*							
			1,361		51	92.7												
Season...	Southern California	6,372	111	319.0	203	393.2	56	106.3	25	43.7	5*				395	862.2		

¹ Newport area includes the coast from San Pedro to San Onofre.² An additional tag was recovered in season 7 (1945-46).³ An additional tag was recovered in season 6 (1946-47).

* Recoveries in the 1946-1947 season for which no weighting factors are available. Not included in the totals.

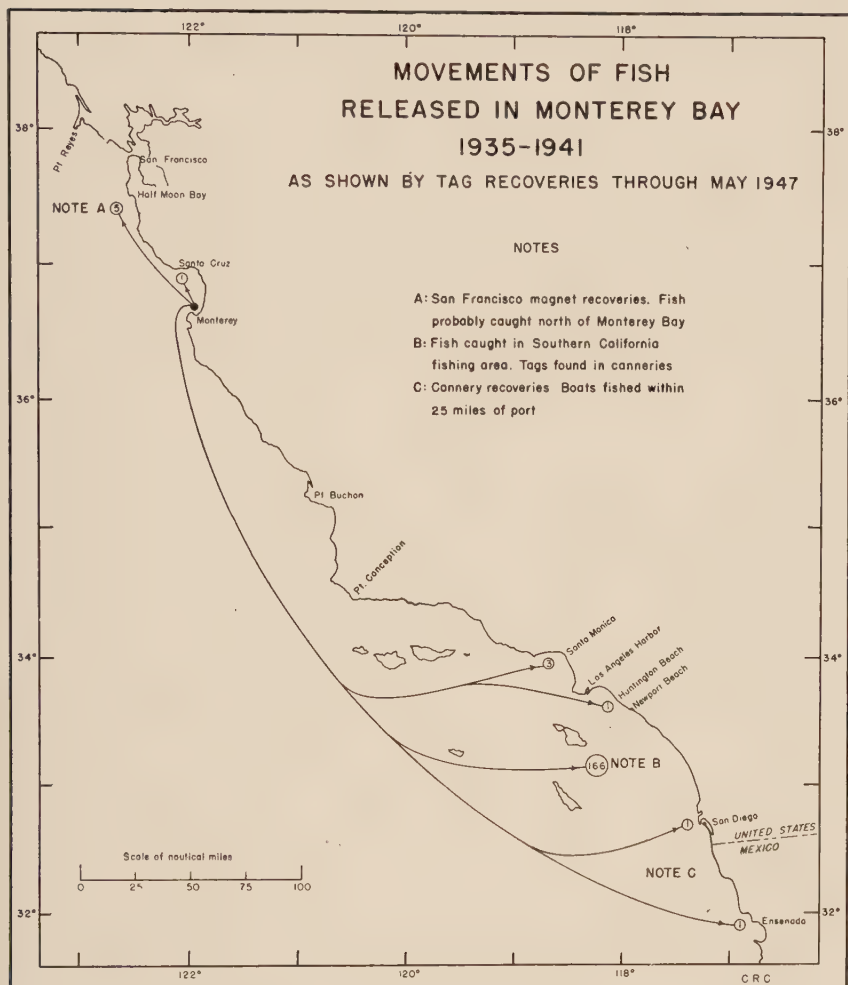


FIGURE 10

movements of Central California fish stems from these three lots which differed in behavior among themselves but showed certain consistent tendencies.

In each case, Southern California returns far outnumbered those in Central California (Table 8). The ratio of Southern California returns to Central California returns does, nonetheless, drop steadily from 5.7 to 1 for the 1937 lot to 3.5:1 for the 1939 lot to 2.5:1 for the 1941 lot (last column, Table 8). The explanation of this shift may lie in the decreased availability of sardines in the Central California area rather than in a change in the habits of mackerel. The number of sardine fishermen catching mixed loads increased in the later years; whether the mackerel population in Central California increased or remained fairly level is not known, but sardines were less available.

TABLE 8
ACTUAL AND WEIGHTED MAGNET RECOVERIES THROUGH MAY, 1947, FROM THE MONTEREY BAY TAG LOTS

Releases		Magnet recoveries, internal tags											
		Los Angeles Harbor											
Year	Number	Season 0		Season 1		Season 2		Season 3		Season 4		Season 5	
		Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted
1937	2,302	2	7.4	14	39.3	16	39.8	9	18.7	2	3.3	1	3.8
1939	482	10	23.2	16	32.0	3	6.8						
1941	1,082	37	65.7	23	39.1	5	9.3	2	5.1	2	3.2		
Totals	3,866	49	96.3	53	110.4	24	55.9	11	23.8	4	6.5	1	3.8

Releases		Magnet recoveries, internal tags											
		San Francisco-Monterey											
Year	Number	Season 0		All following seasons*		Total		Percentage of total tagged		Ratio Southern California: Central California		Total weighted recoveries	
		Actual	Weighted	Actual	Weighted	Actual	Weighted	Southern California	Central California				
1937	2,302	44	112.3	3	5	8	19.6	4.9	0.9				5.7
1939	482	29	62.0	9	1	10	17.8	12.8	3.7				3.5
1941	1,082	69	122.4	34	7	41	49.7	11.5	4.6				2.5
Totals	3,866	142	296.7	46	13	59	87.1	7.7	2.3				3.4

* Ten season 1 returns; one, season 2 (1939 lot); two, season 3 (1941 lot).

The percentage returned of total tagged is far less in both areas for the 1937 lot. A higher tagging mortality may account at least in part for the difference, as this lot represents the first large-scale application of internal tags.

Magnet recoveries by seasons in Southern California are also shown in Table 8. All three lots appeared on the Southern California fishing grounds within a few months of release, the 1937 lot in far fewer numbers than the other two. Returns from this group were heaviest in seasons one and two and persisted through season five. The 1939 lot gave the highest returns in season one and did not reappear after season two. The 1941 lot appeared through season four and gave the greatest number of returns in season zero. In all cases, returns were scattered throughout the fishing season with no observable tendency of the fish to appear in greater numbers in any given month.

Northerly Movements

From Central California

The capture at Santa Cruz by a sportsman of a tagged mackerel released near Monterey some twenty miles to the south constitutes the only definite proof of a northerly movement on the part of these fish. The five recoveries at San Francisco canneries (Table 7) denote some northward movement, but cannot be regarded as positive evidence that the mackerel left the bay as the sardine fleet based at San Francisco sometimes operates within its limits. A study of the catch localities reported by the San Francisco fleet just prior to the recovery of these tags showed that two of the fish probably moved as far as Half Moon Bay, some sixty miles north of Monterey.

From Southern California

Recoveries in the San Francisco-Monterey area demonstrated a substantial northward movement on the part of fish released in Southern California. In all, 81 tags were recovered, 80 of them on cannery magnets. It is notable that all but one of the tags was recovered after the 1940-41 fishing season and that every season since 1941-42 is represented (Table 9). This is partially a result of the small number of fish tagged in the earlier years, but the northern return per 1,000 released is far higher for those tagged since 1940. From 1936 through 1939, 5,109 fish were marked internally in Southern California and one was recovered in Central California. The remaining 80 returns are from the 34,184 fish released in 1940-43. As suggested in the preceding section the increased returns in recent seasons may be associated with a decrease in the availability of sardines rather than with an increased northern population of mackerel.

The single recovery prior to 1941 was of a fish released at Santa Catalina Island in the winter of 1937 and recaptured at Monterey in September, 1938. All of the returns since August, 1941, are from the tag lots released since June, 1940. These recoveries are listed by season in Table 9 where they are compared with Southern California returns over the same period. They represent lots released in the Santa Monica Bay, Newport Beach, Santa Catalina Island, and San Diego areas. There have been no returns from the Santa Cruz Island area, the northern limit of the Los Angeles fishery, but only one lot of 500 fish was successfully tagged in that vicinity. No representatives of five other minor lots,

TABLE 9
SOUTHERN CALIFORNIA TAG LOTS, SHOWING CENTRAL CALIFORNIA RECOVERIES AND THEIR RELATION TO SOUTHERN CALIFORNIA RETURNS

Southern California releases			Recoveries										Los Angeles Harbor, Same seasons, Cannery Magnets		Weighted recoveries per 1,000 tagged	
Date	Place	Number	Central California							Total	Weighted value	Actual	Weighted	Central California	Southern California	
			1941-42	1942-43	1943-44	1944-45	1945-46	1946-47						Central California		
June-Aug., 1940	Newport	4,010	4	0	2	0	0	0	0	6	9.2	46	91.3	2.3	22.8	
October 1940	Santa Monica	631	1	0	0	0	0	0	0	1	1	13	26.7	1.6	42.1	
Dec. 1940-Mar. 1941	Santa Catalina	5,864	17	3	4	0	1	0	0	25	30.9	256	489.6	5.3	83.5	
March-May, 1941	Santa Catalina	3,772	11	2	3	0	1	0	0	17	20.8	196	371.1	5.5	98.4	
Sept., 1941	Santa Monica	2,999	*	2	0	1	1	0	0	3	3.8	38	72.7	1.3	24.2	
Sept., 1941	Newport	2,504	*	0	1	0	0	0	0	1	1.3	13	21.8	0.5	8.7	
Oct., 1941	San Diego	1,119	*	1	0	1	0	0	0	1	1.2	18	33.0	1.1	29.5	
Oct., 1941	Santa Catalina	2,193	*	2	1	1	0	0	0	3	4.0	27	51.7	1.8	23.6	
Nov. 1942-Jan. 1943	Santa Catalina	2,474		*	5	0	3	0	1 ²	9 ²	10.9 ²	106	199.9	4.4	80.8	
February 1943	Santa Monica	2,537		*	5	1	3	1	0	7	10.1	97	196.9	4.0	77.6	
March 1943	Newport	1,361		*	8	0	0	0	0	8	10.6	81	146.4	7.8	107.6	
Totals		29,467	33	10	29	7	1	1	1	81	102.8 ³	891	1,701.1	3.5	57.7	
Aug., 1940-Oct., 1941	Other lots	3,229										29	59.7		18.5	
June 1940-Mar., 1943	Grand totals	32,696	33	10	29	7	1	1	1	81	102.8 ³	920	1,760.8	3.1	53.9	

* Season of release (season 0).

¹ Not a cannery recovery.

² No weighting factor for 1946-47; weighted value based on eight recoveries.

³ Value of 79 cannery magnet recoveries.

two released at Santa Catalina Island and three in the Newport area, were recovered in Central California; a total of 3,229 fish are included in these six lots.

None of the tags was recovered in the season of release, but fish tagged between March and May, the period of scarcity in Southern California, appeared in the Monterey catch the following August. Two lots gave returns over four successive seasons.

Some measure of the magnitude of the movement north from Southern California may be obtained by comparing recoveries in Central California with returns over the same time interval in Southern California. The 79 magnet recoveries in Central California from August, 1941, to March, 1946, have a weighted value of 102.8. Weighted magnet returns from these same lots in Southern California exclusive of those recovered in the season of release total 1,760.8. There were, then, approximately seventeen Southern California returns for each Central California recovery in the seasons after tagging. This is a surprisingly low ratio in view of the huge Southern California catch, which is far more than seventeen times as great as the total mackerel tonnage *reported* delivered at Central California ports. Further, a large portion of this reported tonnage is sold through fresh fish markets with no opportunity for tag recovery. It is evident that the number of mackerel delivered to canneries mixed with sardines is quite appreciable.

In two years, fish were tagged at about the same time in both Central and Southern California. Returns in Central California in the seasons following release were relatively heavier for the locally tagged lots. One of the 3,918 fish released off Southern California in 1937-38 was recovered in Central California, but five of the 2,304 fish released at Monterey during the fall of 1937 were recaptured there after the 1937-38 season. There are no Southern California tag lots comparable with the 1939 Monterey lot, but of the 11,231 fish comprising the 1941-42 Southern California lots, eight were recovered in Central California while seven of the 1,082 Monterey-tagged fish were returned. It is possible that a portion of the fish tagged in Central California simply did not leave the area despite the large number of tags recovered in Southern California.

The relative number of recoveries in Central California from each Southern California lot appears to be positively associated with the number of returns in Southern California in the seasons after release. Several lots virtually disappeared from the Southern California catch after the season of tagging. Central California recoveries from these same lots were likewise few. Other lots giving high returns in Southern California gave similarly high returns in Central California (Fig. 11). Lots with a low rate of return include all those released during the 1941-42 season and that released in the Newport area during June-August, 1940. The inference can be drawn that there was a southerly movement on the part of the fish in the lots giving poor returns, but the lack of facilities for tag recovery in Mexican waters prevents a positive check. These data do not indicate an abnormally high mortality as a result of tagging, for recoveries in season zero were comparable to those from lots giving high returns in the ensuing years.

Central California recoveries were scattered through the sardine season which extends from August to February (Table 10). They reached

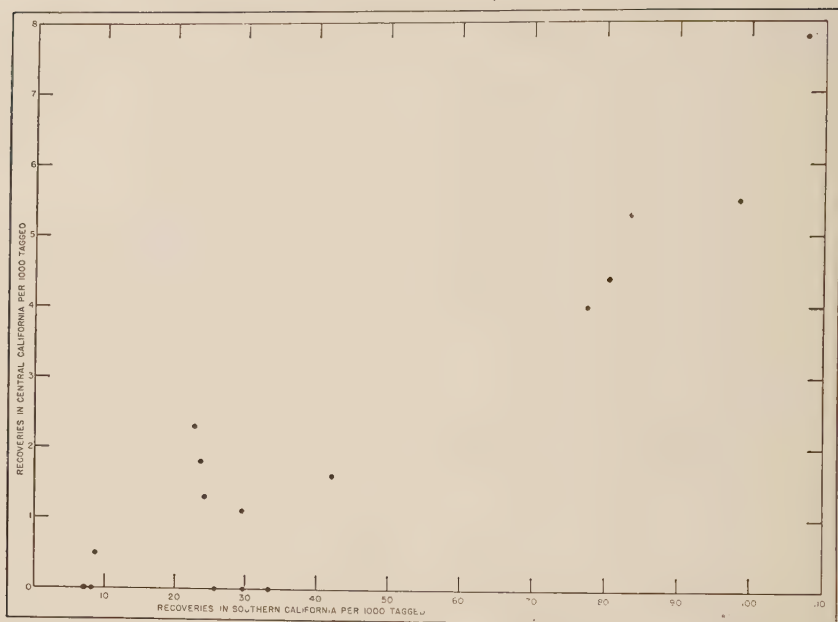


Figure 11. Weighted recoveries in Central California (San Francisco and Monterey) and in Southern California (Los Angeles-Long Beach Harbor) from tag lots released in Southern California, June 1940-March 1943. Southern California recoveries in the season of release are excluded. Data from Tables 5 and 9.

TABLE 10
RECOVERIES BY MONTH AND SEASON IN CENTRAL CALIFORNIA FROM FISH TAGGED IN
SOUTHERN CALIFORNIA, JUNE, 1940-MARCH, 1943

Recoveries							
Month recovered	1941-42	1942-43	1943-44	1944-45	1945-46	1946-47	Total
August.....	9	1	1	0	0	0	11
September.....	7	3	11	0	1	0	22
October.....	2	1	6	4	0	0	13
November.....	11	1	4	2	0	0	18
December.....	3	2	6	0	0	0	11
January.....	1	1	0	1	0	0	3
February.....	0	1	1	0	0	1	3
Totals.....	33	10	29	7	1	1	81

a peak in the fall and dropped off abruptly in January. This was true of fish released in the summer and fall as well as of those released in the winter. Mackerel tag recoveries in general paralleled the sardine catch, falling off as the fishery diminished. Southern California recoveries from these same lots occurred throughout the fishing season. Season one returns tended to be higher in the early part of the season for those lots marked during the summer and fall, and higher in the last half of the season for those marked during the winter. The trend was not pronounced and results were obscured by the time lag between capture of the fish and recovery of the tags. The few returns in later years were widely scattered. There is no evidence in the data of annual migrations of the fish along

the coast, but the fact that a portion of the fish tagged in Southern California during the fishing season were in Central California waters in ensuing seasons coupled with the disappearance of some tag lots suggests that migration has an important bearing on dispersion and availability of the fish.

From Northern Lower California

There were many recoveries in Southern California and one in Central California from the fish released at San Quintin Bay in January, 1940, and at Soledad Bay in October, 1941 (Tables 11 and 12). Returns

TABLE 11

RECOVERIES THROUGH MAY, 1947, FROM FISH RELEASED IN LOWER CALIFORNIA, 1939-1941

Releases			Recoveries				
Date	Place	Number	San Diego	Los Angeles Harbor-Newport Beach	Monterey	San Francisco	Total
Northern section:							
January 1940	San Quintin	3,937	4	76			80
October 1941	Soledad Bay	468	1	22		1	24
Total		4,405	5	98		1	104
Central section:							
Sebastian Viscaino Bay Area							
October 1939	Blanca Bay	137		2			2
January 1940	Chester Rocks	727		4			4
October 1940	(Scattered)	62					
November 1940	Canoas Point	193		3			3
February 1941	Playa Maria Bay	2,699	1	42	2	1	46
February 1941	Santa Rosalia Bay	148					
October 1941	Blanca Bay	1,418	1	32		1	34
October 1941	Playa Maria Bay	2,643		23	2	1	26
October 1941	(Scattered)	90					
Total		8,117	2	106	4	3	115
Thurloe and San Roque Bays							
October 1939	Thurloe Bay	584		3			3
February 1941	San Roque Bay	3,301		31	1	1	33
October 1941	Thurloe Bay	3,984		20	1		21
Total		7,869		54	2	1	57
Total: Central section		15,986	2	160	6	4	172
Total: Lower California		20,391	7	258	6	5	276

from the Soledad lot were particularly heavy when the small number of tagged fish is considered. This lot was unique among those released in Mexican waters in that there were several recoveries in Southern California during season zero. One tag was recovered less than a month from the date of release; this fish traveled at least 100 miles in that time. The 7.7 weighted returns in the season of release represent 1.6 percent of the total number tagged, a surprisingly high percentage in view of the distance involved and the fact that the fishing season was past its peak when this group was marked. Returns persisted through season three (1944-45), the greatest number occurring in season one.

Recoveries from the San Quintin lot were most numerous in season one and appeared thereafter in steadily diminishing numbers through season five (1944-45). While the absolute number of tags recovered is far

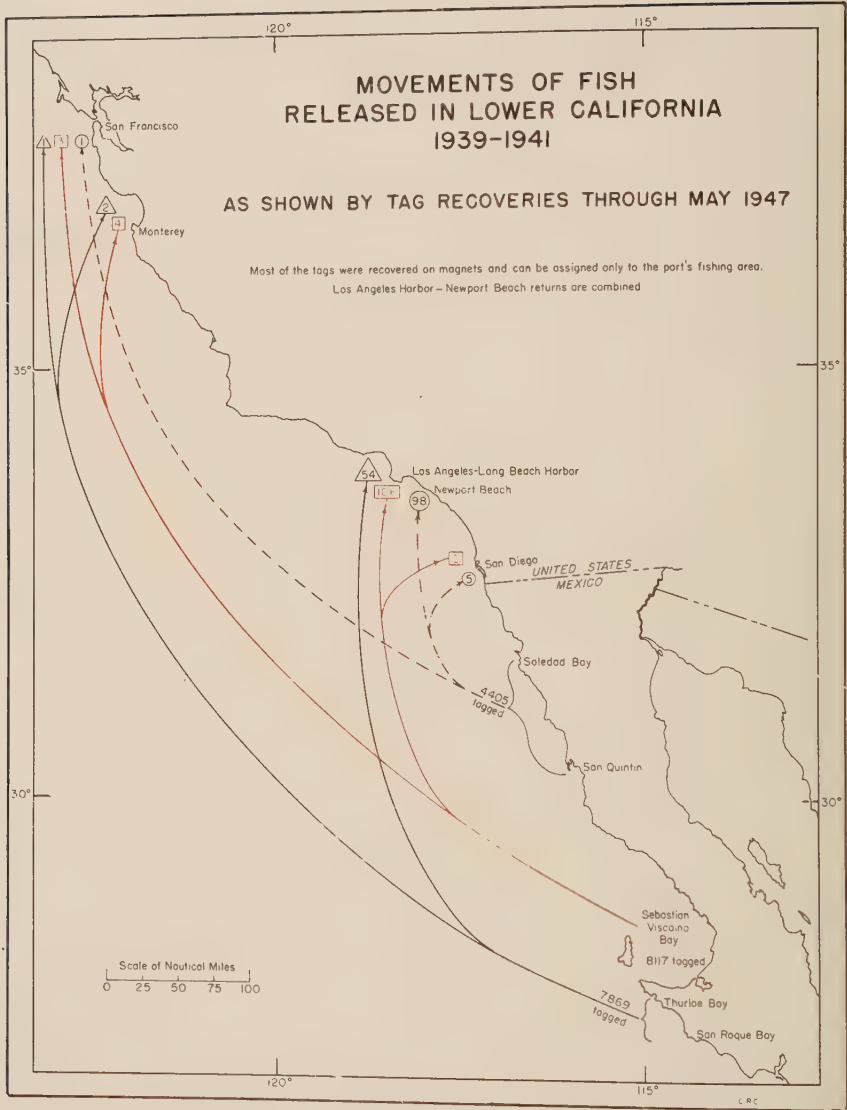


FIGURE 12

TABLE 12—Continued
MAGNET RECOVERIES BY SEASONS IN THE LOS ANGELES HARBOR AREA FROM TAG LOTS RELEASED IN LOWER CALIFORNIA, 1939-1941

Releases			Magnet recoveries at Los Angeles Harbor												
Date	Place	Number	Season 0		Season 1		Season 2		Season 3		Season 4		Season 5		Total Through 1945-46 Season
			Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	
1941-42 Season															
Oct., 1941	Blanca Bay	1,418			14	25.9	12	23.2	6	10.0					32
Oct., 1941	Playa Maria Bay	2,943			13	25.5	5	11.6	2	4.7	1	1.8			21
Oct., 1941	(Scattered)	90													43.6
Season totals		4,151			27	51.4	17	34.8	8	14.7	1	1.8	(1) ¹		53
Area totals		8,117			58	117.8	30	64.5	8	14.7	1	1.8	1+(1)	2.5	98
Thurloe & San Roque Bays 1939-40 Season															201.3
Oct., 1939	Thurloe Bay	584			2	4.3									2
1940-41 Season															4.3
Feb., 1941	San Roque Bay	3,301			14	29.4	5	9.7	5	8.6	1	2.1			25
1941-42 Season															49.8
Oct., 1941	Thurloe Bay	3,984			9	17.0	1	2.0	5	11.4	3	5.6	(2) ¹		18
Area totals		7,869			25	50.7	6	11.7	10	20.0	4	7.7	(2) ¹		45
Totals, Central Section		15,986			83	168.5	36	76.2	18	34.8	5	9.5	1+(3)	2.5	143
															291.5

¹ Figures in parentheses represent 1946-47 season returns for which there are no weighting factors. These returns are not included in the totals.

² An additional tag was recovered in season 6 (1946-47).

greater than for the Soledad lot, the percentage recovered is much less. Weighted returns (Table 11) total 124.8 and equal 3.2 percent of the total tagged, while the 39.0 Soledad returns represent 8.3 percent. The San Quintin lot was exposed to seven full fishing seasons; the Soledad lot to five.

Of the 76 San Quintin tags recovered from all sources in the Los Angeles-Newport Beach area (Table 11), 49 appeared in October, November and December. The remainder were scattered through the balance of the fishing season. Of the 22 returns from Soledad all but one occurred before January.

From Central Lower California

With one exception, there were returns from every day's tagging in this area which involved over 150 fish. Recoveries totaled 158 in Southern California and ten in Central California, (Tables 11 and 12 and Fig. 12) and demonstrated clearly that Mexican fish from at least as far south as San Roque Bay entered into the Southern California fishery. None of the tags was recovered in the season of release, but a summary of Southern California recoveries from the heavy 1941 tagging shows that some of the fish were present on the fishing grounds throughout most of the ensuing seasons. However, recoveries from the February, 1941, lots (A, Table 13) showed a concentration in October and November while those released in October, 1941, (B, Table 13) appeared more heavily in November and December.

TABLE 13

RECOVERIES BY-MONTH AND SEASON IN THE LOS ANGELES-NEWPORT BEACH AREA FROM FISH RELEASED IN CENTRAL LOWER CALIFORNIA DURING 1941

Group A, Including 6,148 Fish, Was Marked in February; Group B, 8,135 Fish, in October

Month recovered	Recoveries											
	1941-42		1942-43		1943-44		1944-45		1945-46		1946-47	
	A	B	A	B	A	B	A	B	A	B	A	B
August.....	1	--	0	0	0	1	--	0	--	--	--	1
September.....	4	--	1	1	0	1	1	2	--	--	--	6
October.....	17	--	3	5	0	3	--	3	--	3	1	21
November.....	15	--	7	14	3	4	--	2	--	--	2	25
December.....	5	--	3	11	1	6	--	3	--	--	--	9
January.....	2	--	3	4	0	1	--	3	--	1	--	5
February.....	2	--	1	2	1	1	--	0	--	--	--	4
March.....	2	--	0	0	0	1	--	0	--	--	--	2
Totals.....	48	0	18	37	5	18	1	13	0	4	1	73

All of the Central California recoveries were from fish released in 1941 (Table 11). The ten returns have a weighted value of 12.8, contrasted with 291.5 weighted returns in Southern California from the central section lots. (The four 1946-47 returns in Southern California are not included as weighting factors are not available.) The recoveries were scattered widely through the sardine season as shown in Table 14.

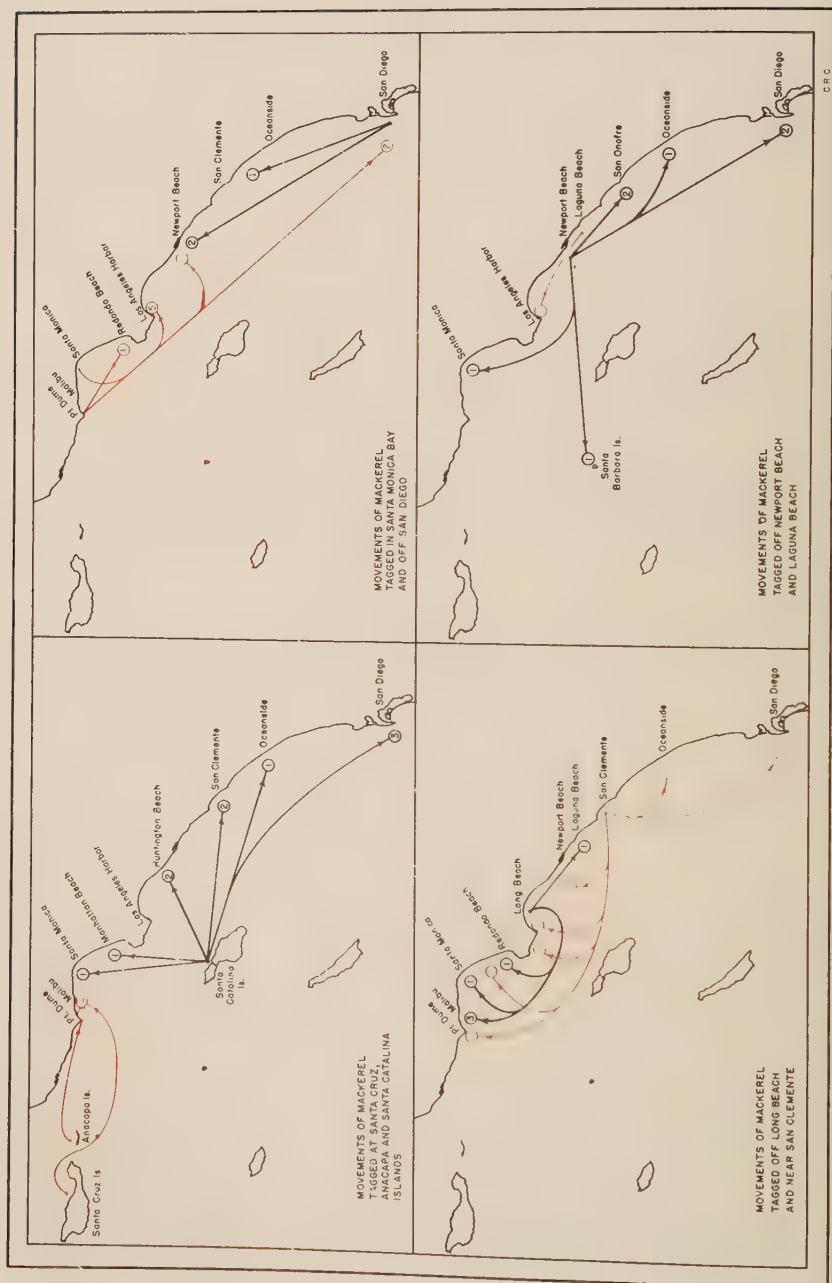


FIGURE 13. Known movements of mackerel released and recaptured in Southern California waters. Only movements of over twenty miles are shown

TABLE 14
RECOVERIES BY MONTH AND SEASON AT SAN FRANCISCO AND MONTEREY FROM FISH
RELEASED IN CENTRAL LOWER CALIFORNIA

Month recovered	Recoveries				Total
	1941-42	1942-43	1943-44	1944-45*	
October.....			2	1	3
November.....	1				1
December.....			2		2
January.....		1			1
February.....	1		1		2
March.....		1			1
Totals.....	2	2	5	1	10

* There have been no recoveries since 1944-45.

Five of the tags were recovered in season two, three in season one and one each in seasons four and five. Fish released in Southern California waters appeared in Central California preponderantly in season one.

Returns from fish released in the two geographical portions of the central section were of entirely different magnitude. Tagging was accomplished in both areas on three research trips; in each case, returns from the Sebastian Viscaïno area were far more numerous (Table 15). There

TABLE 15
RECOVERIES FROM MACKEREL RELEASED THE SAME MONTH IN THE TWO SECTIONS OF
CENTRAL LOWER CALIFORNIA

Releases			Recoveries			
			Actual		Per 1,000 tagged	
Date	Place	Number	Southern California	Central California	Southern California	Central California
October 1939.....	Sebastian Viscaïno.....	137	2		14.6	
	Thurloe-San Roque.....	584	3		5.1	
February 1941.....	Sebastian Viscaïno.....	2,847	43	3	15.1	1.1
	Thurloe-San Roque.....	3,301	31	2	9.4	0.6
October 1941.....	Sebastian Viscaïno.....	4,151	56	4	13.5	1.0
	Thurloe-San Roque.....	3,984	20	1	5.0	0.3
Totals.....	Sebastian Viscaïno.....	7,135	101	7	14.2	1.0
	Thurloe-San Roque.....	7,869	54	3	6.9	0.4

were 108 returns from the 7,135 Sebastian Viscaïno fish but only 57 from the 7,869 released at Thurloe and San Roque Bays. The difference is highly significant ($P < .001$) when measured by the chi-square test.

As shown in Table 11, Southern California returns from all the lots were heaviest in the first season after tagging. However, the lot of 1,418 fish tagged at Blanca Bay in October, 1941, included a group of about 1,000 young fish ranging from fifteen to twenty centimeters in length, the smallest tagged in the entire program. Maximum returns from this

group occurred in the second season. Total recoveries were high in proportion to the number marked; apparently the tagging operation did not cause undue mortality.

The only sizeable day's tagging from which there were no recoveries was a group of 669 fish released at Thurloe Bay in October, 1941. This group forms part of the tag lot of 3,984 individuals which was released in four groups over a three-day period. Total recoveries from the lot were only 21, and the lack of returns from the one group is not statistically significant.

Of the five lots including more than 1,000 fish tagged in central Lower California waters, two (Playa Maria and Thurloe, October, 1941), were represented in the Southern California catch in each of the five seasons to which they were exposed. The Blanca Bay lot, also released in October, 1941, did not reappear in season four. The San Roque lot, out six seasons, appeared in the first four. The Playa Maria lot, tagged at the same time, gave Southern California returns in seasons one and two and again in season six. However, a tag from this lot was recovered in Central California in both seasons three and four. Returns generally decreased from season to season. The 1941 Thurloe lot was an exception, returns dropping from nine in season one to one in season two, while third, fourth and fifth season returns totaled five, three and two. *

Movements Within Southern California

Very few of the tag returns can be used to show definite movements within the Southern California fishing area. Both sport and commercial fishermen, especially the former, turned in tags with specific data as to both place and time of capture, but most of these were taken within a few weeks of release and at or near the point of tagging. Cannery recoveries at San Diego demonstrated movement to within twenty-five miles of port, for the local fleet operated within that radius. Returns at Los Angeles Harbor and Newport Beach canneries proved little or nothing because of the widespread area covered by their fleets. Known movements of over twenty miles are shown in Figure 13. These indicate a general dispersion at least throughout those portions of Southern California in which a reasonably heavy sport fishery exists. Sport fishing north of Santa Monica Bay is sporadic and the lack of recoveries in the area is meaningless. The single offshore recovery at Santa Barbara Island resulted from the fortuitous discovery of an external tag by a crew member on a purse seiner, the only return from this source. Almost all of the recoveries shown on Figure 13 were of opercular tags except at San Diego canneries. All were recovered within fourteen months and a majority within six months of the date of release. One fish was recaptured in Santa Monica Bay, 21 miles from the point of release off Long Beach, only 20 hours after it was tagged.

These returns provide scanty information as to the movement of given groups of fish. Because of the lack of opportunity for recovery north of Santa Monica Bay and south of San Diego, all recoveries from lots marked in those areas perforce showed movement in only one direction. Some of the lots marked in the Long Beach-Newport area and at

Santa Catalina Island seemed to spread both north and south of the place of release; returns from other lots indicated movement in only one direction. Spot returns were, however, far too few to demonstrate anything other than the fact that fish released at one locality in Southern California were likely to be retaken at any other locality within the next year.

Returns within twenty miles of the point of release are contrasted with the more distant recaptures in Figure 14. The data indicate that

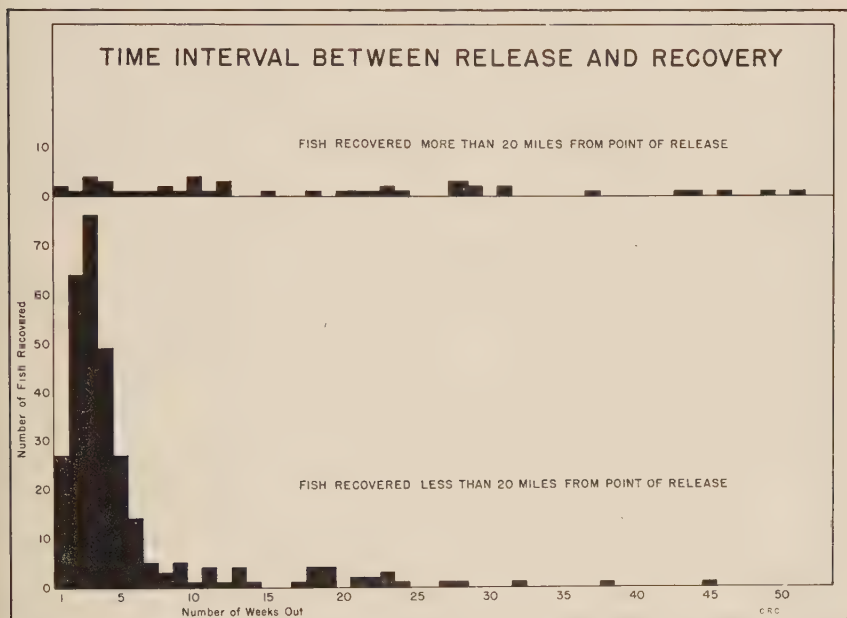


FIGURE 14. Number of recoveries by weeks during the first year from fish released and recaptured in Southern California.

most of the fish tended to remain for several weeks close to the point of release, though a few individuals moved some little distance almost at once. While nearby returns fell off rapidly after the third week, they exceeded distant recoveries until after the twentieth. The few recaptures in the first week reflect an apparent disinclination of the fish to take a hook in the days immediately following tagging.

In two instances the number of recaptures near the point of release was markedly increased by fishermen who were definitely fishing for tagged mackerel. A commercial fisherman operating a small net boat worked a limited area off Long Beach for several weeks simply because he knew that tagged mackerel had just been released in the vicinity. The reward then offered for the return of marked fish made it worth his time to examine his catch for tags and to continue fishing in the area, although fishing for untagged fish was equally good at several other places. On several days he found a dozen or more tags. He also

discovered many fish which had obviously recently lost a tag and others on which the tag had nearly worked free. This provided the first clue as to the imperfections in the opercular tags. In all, this man and his small crew seined 135 fish with tags in place out of 551 marked in the area. The second example involved sport fishermen at Malibu Beach who found that they could often earn their expenses by fishing specifically for tagged mackerel.

Movement by Size

In an effort to determine whether and to what degree a differential size movement took place, all magnet returns were separated into two groups. The first included tags recovered from fish under thirty centimeters in length at the time of marking; the second, those from fish thirty centimeters or more. The point of division into the "small" and "large" categories was chosen rather arbitrarily for convenience in handling the data; it does in most cases separate the various lots into roughly equal size groups.

Some evidence of a differential southerly movement is found in Southern California returns from fish released in Monterey Bay in the fall months of 1937, 1939, and 1941. The larger sizes tended to appear first, always predominating in the season of release, while maximum returns from small fish occurred in seasons one or two (Table 16). Central California returns from Southern California tag lots show no evidence of a differential movement. The lots released since June, 1940, consisted of 32,696 fish and produced 80 Central California recoveries (Table 9). Of these, 15,683 were "small" when marked and 16,907 "large." (Those remaining were not measured.) In season one, tags from 29 small and 27 large fish were recovered in Central California. Total returns included tags from 42 small and 38 large fish. Recoveries from small fish released in the 1940-41 and 1941-42 seasons were considerably heavier than those from large but the reverse was true of fish tagged in the 1942-43 season.

No significance can be attached to returns by size from fish released in northern Lower California. The San Quintin lot included very few small fish. The Soledad lot consisted of only 295 small and 172 large individuals. Returns were nearly equal each season from both groups; total weighted returns of Soledad fish are 19.1 for small and 19.9 for large fish.

Returns from the very small fish (which formed in effect a third size group) marked at Blanca Bay were appreciably greater than returns from the larger sizes (Table 17). This suggests a heavier influx on the part of these juveniles, though nothing beyond the inference can be drawn on the basis of a single tag lot. Returns from other small fish released in Sebastian Viscaïno Bay exceeded those from large by a perhaps significant amount ($P = .035$). Returns from both size groups released in Thurloc and San Roque Bays were of the same magnitude.

TABLE 16
THE MONTEREY BAY TAG LOTS SHOWING SOUTHERN CALIFORNIA MAGNET RECOVERIES SEPARATED ON A SIZE BASIS ¹

Releases			Magnet recoveries, Los Angeles Harbor												Weighted recoveries as a percentage of total tagged		
Year	Size	Number	Season 0		Season 1		Season 2		Season 3		Season 4		Season 5			Total	
			Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted		Actual	Weighted
1937	Small	1362			7	18.7	13	32.5	7	14.3			1	3.8	30	72.6	5.3
	Large	918	2	7.4	7	20.6	3	7.3	2	4.4					14	39.7	4.3
1939	Small	353	2	4.6	9	17.8	3	6.8							14	29.2	8.3
	Large	127	8	18.6	7	14.2									15	32.8	25.8
1941	Small	470	7	10.7	7	14.2	2	4.4	1	2.3	1	1.7			18	33.3	7.1
	Large	608	30	55.0	16	24.9	3	4.9	1	2.8	1	1.5			51	89.1	14.7

¹ "Small" fish are those under 30 cm. body length when marked and "large" those 30 cm. or more. (The total tagged does not equal the lot totals in Table 8 as a few of the fish were not measured.)

TABLE 17
THE TAG LOTS RELEASED IN CENTRAL LOWER CALIFORNIA SINCE OCTOBER, 1939
Showing Southern California Magnet Recoveries Separated on a Size Basis¹

Releases		Magnet recoveries, Los Angeles Harbor												Weighted recoveries as a percentage of total tagged
Size	Number	Season 1		Season 2		Season 3		Season 4		Season 5		Total		
		Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	Actual	Weighted	
Sebastian Viscaino Bay Area														
Small	1,341	14	25.9	11	21.4	6	10.0					31	57.3	
Blanca Bay, Oct., 1941 ²	1,397	13	26.5	4	8.9	1	2.4			1	2.5	19	40.3	
All others														
Totals	2,738	27	52.4	15	30.3	7	12.4			1	2.5	50	97.6	
Large	5,367	31	65.4	15	34.2	1	2.3	1	1.8			48	103.7	
Thurloe-San Roque Bays														
Small	1,476	7	15.3	1	1.3	1	2.4					9	19.0	
Large	6,378	18	35.4	5	10.4	9	17.6	4	7.7			36	71.1	

¹ "Small" fish were under 30 cm. body length when tagged; "large," 30 cm. or more.
(The totals do not equal the lot totals in Tables 11 and 12 as a few fish were not measured.
1946-47 returns are omitted as weighting factors are not available).

² Extremely small fish.

Distant Regions and the Southern California Fishery

Some measure of the relative importance to the Southern California fishery of the several regions in which fish were tagged was obtained from a study of tag returns over several seasons.

One comparison was made by deducting season zero returns from the number tagged in each region and then expressing total recoveries in the following seasons as a percentage of the number remaining. The adjustment was first made for season zero returns in order that the long-term recovery rates could be put on a relatively equal basis for all regions. The fish marked in Southern California were exposed to initial seasons of varying lengths and to fisheries of varying intensities. Those released in Central California were subject to some fishing but almost none of those tagged in Mexican waters reached the fishing grounds until season one. This method gives a minimum estimate of the proportion of survivors recaptured for it takes no account of deaths due either to natural causes or to the tagging operation. Data are shown in Table 18. Returns in seasons 1-3 only were used because there are no correction factors for fourth season (1946-47) returns from Southern California lots released in 1941-42. The two northern Lower California lots at Soledad Bay and San Quintin were treated separately despite the small number of fish tagged at Soledad because the recovery rates were quite different. The results are reasonably consistent except for Southern California releases in 1941-42. Apart from this, returns tended to decrease as distance from the fishing grounds increased, with Southern California-tagged fish making the greatest contribution over the period of years. The map (Figure 15) shows the distance from the center of each tagging area to the nearest limit of the fishing grounds and the percentage of long-term recoveries in Southern California.

The fish tagged in Southern California in 1941-42 simply disappeared and over-all returns after the season of release were on the level of those from Sebastian Viscaino Bay fish released that season. As discussed previously, recoveries in Central California were also low and a southward movement can be postulated. A high tagging mortality cannot account for the difference in view of the numerous season zero returns. The aggregate recovery rate for Southern California releases was of course lowered appreciably by this disappearance.

The figures presented thus far have made no allowance for tagging mortality. If we adjust the number of releases to include the minimum (23 percent) and the average (40 percent) rates of tagging mortality before deducting season zero returns, a better picture is had of the actual recovery rates. The minimum gives perhaps the best available estimate of the actual number of effectively tagged fish (see page 24). Assuming no mortality, 23 percent and 40 percent mortality, the percentage of survivors recaptured in seasons 1-3 is:

Region	Tagging mortality rate		
	None	23%	40%
Monterey -----	5.1	6.8	8.8
Southern California -----	7.6	10.5	14.8
Soledad Bay -----	6.8	8.9	11.5
San Quintin -----	3.1	4.0	5.1
Sebastian Viscaino Bay -----	2.4	3.2	4.0
Thurloe-San Roque Bays -----	1.0	1.4	1.7

TABLE 18
COMPARISON OF LONG TERM MAGNET RECOVERIES AT LOS ANGELES HARBOR FROM INTERNALLY-TAGGED FISH RELEASED IN THE SEVERAL GEOGRAPHIC AREAS ¹

Season	Releases Region	1 Number	2 Total magnet recoveries in season of release (Season 0)		4 Maximum survivors end of season of release Col. 1—Col. 3	5 Los Angeles Harbor magnet recoveries seasons 1-3		7 Percent of maxi- mum survivors recovered Col. 6×100 Col. 4
			Actual	Weighted		Actual	Weighted	
1937-38	Monterey	2,302	52	17.8	2,284.2	39	97.8	4.3
	Southern California	3,918	47	238.6	3,679.4	159	484.2	13.2
1939-40	Monterey	432	19 ²	39.8	442.2	19	38.7	8.8
	Southern California	705			705.0	37	78.3	11.1
	San Quintin	3,937			3,937.0	60	120.3	3.1
	Sebastian Viscaino Bay	864			894.0	6	13.3	1.5
	Thurloe-San Roque	584			584.0	2	4.3	0.7
1940-41	Southern California	15,093	1,791	3,764.0	11,329.0	512	980.9	8.7
	Sebastian Viscaino Bay	3,102			3,102.0	38	82.8	2.7
	Thurloe-San Roque	3,301			3,301.0	24	47.7	1.4
1941-42	Monterey	1,082	71 ²	107.6	974.4	30	53.5	5.5
	Southern California	11,231	1,255	2,524.0	8,707.0	115	220.7	2.5
	Soledad Bay	468	4	7.7	460.3	16	31.3	6.8
	Sebastian Viscaino Bay	4,151			4,151.0	52	100.9	2.4
	Thurloe-San Roque	3,984			3,984.0	15	30.4	0.8
1942-43	Southern California	6,372	111	319.0	6,053.0	284	543.2	9.0
Totals	Monterey	3,866	95	165.2	3,700.8	88	190.0	5.1
	Southern California	37,319	3,184	6,845.6	30,473.4	1,107	2,307.3	7.6
	Soledad Bay	468	4	7.7	460.3	16	31.3	6.8
	San Quintin	3,937			3,937.0	60	120.3	3.1
	Sebastian Viscaino Bay	8,117			8,117.0	96	197.0	2.4
	Thurloe-San Roque	7,869			7,869.0	41	82.4	1.0

¹ Data from Tables 6, 8, and 12.² Includes magnet recoveries at San Francisco and Monterey.

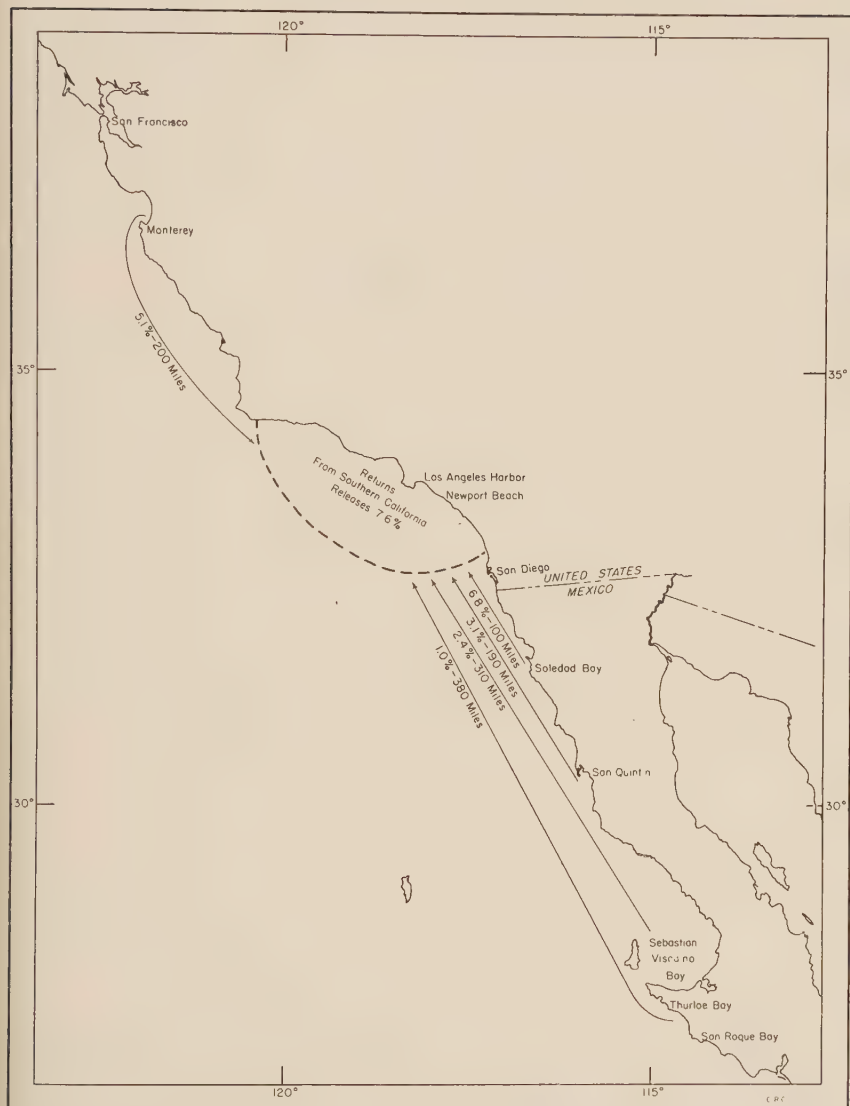


FIGURE 15. Weighted returns at Los Angeles—Long Beach Harbor in seasons 1-3 expressed as a percentage of the number tagged less season zero returns, and the approximate distance traveled by the fish to the nearest limit of the fishery. No allowance has been made for tagging mortality. Data from table 18.

An estimate of the apparent survival rates and of the length of time required before the fish from the several areas became equally available to the fishery was obtained from season-to-season returns. In Table 19, weighted Los Angeles Harbor returns per 1,000 releases are shown for each season through the fourth. This eliminates the 1942-43 Southern California lots, for which there are no fourth season weighting factors. The survival rates were determined from the formula (discussed on page 58:

$$\frac{\Sigma \text{ returns seasons 1-3}}{\Sigma \text{ returns seasons 2-4}}$$

Soledad and Southern California showed the lowest survival rates (26 and 27 percent), the other regions ranging from 41 to 48 percent. The figures must not be regarded as "true" survival rates, but rather as mirroring the effect of a gradual influx from the outlying regions, and it is suspected, an appreciable departure from the grounds on the part of the Southern California fish.

The season-to-season data indicate that Southern California and Soledad fish were dominant in season one and that returns tended to equalize in season two. Thereafter, returns, though few in number, were of the same magnitude regardless of the region of release. Disregarding the season of release, returns dropped off uniformly from year to year except for Soledad Bay, where the number tagged was small, and Thurloe-San Roque Bays, the southernmost tagging region.

The overall picture is altered slightly if we take into account a minimum tagging mortality of 23 percent and then express returns each season as a percentage of the maximum survivors at the season's start

(e.g., percentage recovered season 0 = $\frac{\text{returns season 0}}{\text{number tagged} \times 0.77}$, percentage recovered season 1 = $\frac{\text{returns season 1}}{\text{number tagged} \times 0.77 - \text{returns season 0}}$, etc. Table

20). Returns from the three northern regions were dominant through season three and it was only in the fourth season that the scanty returns from each region approached the same magnitude.

TABLE 20
WEIGHTED RETURNS AT LOS ANGELES HARBOR

Expressed as a Percentage of the Maximum Survivors at the Start of Each Season. An Initial Tagging Mortality of 23 Percent Is Included. Returns Each Season Are Deducted From the Number Surviving at the Beginning of the Season Before Calculating the Percentage Recovered in the Following Season ¹

Region	Percentage recovered of survivors at beginning of each season				
	Season 0	Season 1	Season 2	Season 3	Season 4
Central California.....	3.2	3.8	2.0	0.9	0.2
Southern California.....	26.1	7.4	2.2	0.6	0.1
Soledad Bay.....	2.1	6.6	1.0	1.5	-----
San Quintin.....	-----	2.4	1.4	0.2	0.1
Sebastian Viscaïno Bay.....	-----	1.9	1.0	0.2	0.03
Thurloe-San Roque Bays.....	-----	0.8	0.2	0.3	0.1

¹ Data from Table 19.

Summarizing, each region contributed about the same amount to the fishery after a lapse of several years, but the total contribution of the distant regions was far less over the entire period.

In making these comparisons, it must not be overlooked that the fish tagged in Southern California not only reappeared in quantity but provided as well the basis of the fishery in the season of tagging. Weighted returns in season zero generally exceeded 20 percent if the fish were exposed to more than a month or two of the initial season, and over 40 percent of the fish marked at Santa Catalina Island during the winter of 1940-41 were recaptured by the end of March, 1941.

It is unfortunate that tagging operations had to be carried on in the distant regions almost exclusively during the heaviest part of the Southern California fishing season. As a result, we know nothing of the role played by the population to be found there during the spring and summer. That many of the fish found as far distant as San Roque while the Southern California fishery was still in progress did appear in later years on the fishing grounds is indicative of the importance of Mexican waters to the California industry. That Monterey fish appeared in Southern California in the season of release and made a heavy contribution over a period of years shows that individuals found in northern waters move freely into Southern California.

Without facilities for tag recovery in Mexico, no proof of cyclic movement is possible. That the populations in the regions covered by the program intermingle has been demonstrated and some measure of the relative importance of these areas has been obtained. The paucity of returns from the Thurloe-San Roque area make it seem likely that the adult population present during the winter months still farther south contributes a negligible quantity to the Southern California fishery. The tagging program did not, however, answer the question as to what becomes of Southern California fish during the months when they are no longer present in fishable numbers on these grounds. The lack of any abundance of mackerel to the north at this time leaves a southern migration the only tenable explanation, but no clue as to how far south the fish move can be obtained without tagging in Mexican waters during the spring.

STUDIES OF ABUNDANCE

Methods

Two avenues of approach were followed in attempts to obtain a valid measure of abundance from tag returns. Several sources of error, some apparent from the start and others found in the course of analysis, proved sufficient to cloud the results and forced the conclusion that, insofar as the mackerel fishery is concerned, returns from the tagging experiments could not alone be used for population estimates.

The initial study followed generally the method set forth by Ricker (1944) and applied by Clark and Janssen (1945) to returns from sardine tagging experiments. A subsequent elaboration by Ricker (1948) designed to overcome some of the difficulties encountered in applying the earlier technique permitted a second analysis including these later concepts.

Both methods presume a uniform distribution of tagged fish in the population, and reasonably constant fishing effort, fishing mortality, and

natural mortality throughout the time period under survey. Further, there must be a measure of tag loss due to death as a result of tagging, shedding of tags, and incomplete recovery. Given these circumstances and measures, estimates of mortality from natural causes and from fishing, and of the absolute size of the exploited population are theoretically obtainable from tag returns over a series of equal time intervals.

The discussion in preceding sections has indicated that the basic premises are at best only partially fulfilled in this instance. The mackerel fishery is concentrated in a small part of the year, reaching its peak in October and November. By adopting the fishing season as the time interval, the midpoint coincides reasonably well with maximum fishing intensity, and the error caused by unequal distribution of fishing and natural mortality is believed minimized.

Complete dispersion of tagged fish in the population had perforce to be assumed. The data presented in the discussion of migrations demonstrated that this condition did not prevail, at least for the first year or two after release. Further, tagging was not evenly distributed throughout a given season either as to time or in relation to the incidence of fishing but was accomplished as circumstances permitted. The Southern California tag lots were exposed to initial seasons of varying lengths, were released in areas subject to varying degrees of fishing intensity, and could not be presumed to be equally available to the fisherman. Returns in the season of tagging consequently were not comparable with returns in later seasons and could not be directly utilized.

No measure of fishing intensity was calculated. The disruption of the fishery during the war years would have made its determination extremely difficult, and of such doubtful accuracy that it was decided the results would not be worth the required expenditure of time and manpower.

The validity of the correction factors for tagging mortality and for tag loss have been assessed. The measure of tagging mortality is especially open to question. Both the minimum rate of approximately 23 percent and the average of 40 percent were applied in estimating the number of survivors.

Symbols and basic formulae (from Ricker, 1948) used in the following discussion include:

s	The total annual survival rate
a	The total annual mortality rate, or expectation of death
m	The total annual mortality rate from fishing
n	The total annual mortality rate from natural causes
μ	The annual expectation of death from fishing
i	The total instantaneous mortality rate
p	The total instantaneous mortality rate from fishing
q	The total instantaneous mortality rate from natural causes
$R_1 \dots$	Returns each season with R_1 = returns in the season of release
$a = m + n - mn = 1 - s$	
$i = p + q$	
$\frac{i}{a} = \frac{p}{\mu}$	
$-\frac{i}{a} = -\frac{p}{\mu}$	

In the initial study the total effect of fishing mortality and natural mortality, or the rate of decline (a), was measured by fitting a straight line to the logarithms of recoveries in each time interval and determining the value of the regression coefficient. The antilogarithm of this value,

representing the average survival rate (s), was then subtracted from 1.00 to convert it into the rate of decline.

Given the rate of decline, an estimate of annual fishing mortality (m) independent of annual natural mortality (n) was calculated by determining the number of tags which would have been recovered at zero time, when only fishing mortality would be operative, and expressing this figure as a percentage of the number of tagged fish then available.

A measure of the annual natural mortality rate independent of annual fishing mortality was then derived from the formula:

$$m + n - \frac{mn}{100} = a.$$

To find the annual expectation of death from fishing, μ (the "rate of exploitation" or the percentage of the population represented by the catch), the instantaneous mortality rates i , p and q corresponding to the seasonal rates a , m and n had first to be determined. These were read with sufficient accuracy from Ricker's tables.

$$\text{Then, } \mu = \frac{pa}{p + q} \text{ or } \frac{pa}{i}.$$

Since returns in season zero could not be used, the value of "a" was determined from returns in the following seasons, and zero time represented the beginning of season one. A great potential error revolved around the determination of the number of tagged fish available at zero time—the total tagged less those dying as a result of tagging, those shedding their tags and those captured or dying of natural causes prior to the start of season one. A suitable correction existed only for those captured, it being the weighted returns in season zero. Natural mortality was unmeasurable, and, since this loss of tags could not be deducted from the number of available tags, the value obtained for fishing mortality was lowered by an unknown but probably significant amount. The rate of exploitation as derived from this method is, consequently, a minimal estimate.

The antilogarithm of the intercept was not considered as representing theoretical recoveries at time zero. It has been assumed that the total recoveries in each season to which the trend lines were fitted were in effect midpoints of class intervals and that therefore the antilogarithm of the value of y when $x = 0.5$ is the true measure of theoretical recoveries at the instant season one commences.

The second method as presented by Ricker (1948) is designed to overcome the error introduced when tagging was done throughout the year and returns in the year of tagging could not be used in making direct estimates of mortality rates. As in the first method, the mortality rate estimated from recoveries in the years after release (a_2) is regarded as representing the true rate for the population as a whole. Further, the instantaneous rate of natural mortality (q) is assumed to be the same for all years, though the other statistics for the year of release may vary from those of the following years. The value of μ_2 , the best estimate of the "true" rate of exploitation cannot be determined directly, but Ricker presents two formulae from which it may be found through a series of trials. In applying this method the survival rate for the years after that of marking (s_2) was first calculated from the formula

$$s_2 = \frac{R_3 + R_4 + \dots R_n}{R_2 + R_3 + \dots R_{n-1}}.$$

The value of a_2 ($1.0 - s_2$) was determined and the corresponding instantaneous mortality rate (i_2) was read from Ricker's tables. The estimate of μ_2 was then obtained by taking trial values of a_1 and i_1 , the seasonal and instantaneous mortality rates in the season of tagging, and using these assumed rates in the following formulae taken from Ricker

$$(1) \quad \mu_2 = \frac{i_1 (R_2 + R_3 + R_n)}{a_1 N (1 + s_2 + s_2^2 + s_2^{n-2})}$$

$$(2) \quad \mu_2 = \frac{a_2}{i_2} \left(i_2 - i_1 + \frac{R_1 i_1^2}{N(i_1 - a_1)} \right)$$

until equivalent values of μ_2 were obtained.

Application

Both methods were applied to magnet returns at Los Angeles Harbor from the tag lots released in Southern California, to returns from all releases in a given season, and to recoveries from various groupings of tagging seasons. Final studies centered on releases in the 1940-41, 1941-42 and 1942-43 seasons, eliminating the two early lots as they represented but two fishing areas over a period of three seasons. Lots released in Central and Lower California were not handled separately for a number of reasons. It was felt that the latter could not be utilized directly because of the gradual entry of the fish into the fishery, a factor which would result in an artificially reduced rate of decline. The small number of releases in Monterey Bay made use of these lots seem unwarranted, particularly as the 1937 group entered the fishery slowly and the 1939 fish disappeared after the second season. Lots from these regions were used in combination with Southern California material.

In all but preliminary work, calculations were based on the recoveries in the first three full fishing seasons (seasons one through three) to which the fish were exposed. Returns beyond season three were very few (though the rate of decline was altered insignificantly when season four returns were included) and there were no weighting factors for season four recoveries from the 1942-43 lots.

Results and Conclusions

Regardless of the grouping of the tag lots and regardless of the area of release and the assumed level of tagging mortality, the results were consistent in one respect: the rate of exploitation was remarkably low in relation to the total rate of decline. This held true whether Southern California lots were treated separately or in conjunction with Lower and Central California lots and when it was assumed that correction factors greatly underestimated actual returns. Table 21 shows typical rates determined for Southern California releases in the 1940-41—1942-43 seasons. Considering all releases in this period, at the 40 percent level of tagging mortality minimal μ derived from the first method is 12 percent and the best estimate of μ_2 from the second method is 19 percent. Taking the three tagging seasons separately, μ_2 varies from 6 percent to 28 percent. The relative differences are about as would be expected, the low value being associated with the scanty returns from the 1941-42 lots and the high with the heavy returns from the 1940-41 lots. The rate of decline ranges from .67 for 1941-42 and 1942-43 when determined by method one to .83 for 1940-41 as determined from method two. The rate as

TABLE 21
MORTALITY RATES FOR FISH TAGGED IN SOUTHERN CALIFORNIA AS DETERMINED FROM AN ANALYSIS OF TAG RETURNS AT LOS ANGELES HARBOR

Season of tagging	Number of fish tagged	Rate of decline, a		Rate of exploitation, μ				Annual natural mortality rate, n			
		Method 1 Method 2		Tagging mortality = 23 percent		Tagging mortality = 40 percent		Tagging mortality = 23 percent		Tagging mortality = 40 percent	
		Method 1	Method 2	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
1940-41-----	15,093	.82	.83	.13	.20	.21	.28	.76	.74	.72	.69
1941-42-----	11,231	.67	.79	.02	.06	.03	.08	.66	.76	.65	.75
1942-43-----	6,372	.67	.70	.09	.135	.12	.17	.61	.62	.59	.60
Totals-----	32,696	.74	.78	.08	.14	.12	.19	.70	.72	.68	.69

determined from a straight line fitted to the logarithms of seasonal returns is less in each instance, though the difference is great only for the 1941-42 releases.

Assuming for the moment that these measures are fairly accurate estimates, seasonal natural mortality independent of fishing (n) is found to be on the order of 70 percent for the experiment total regardless of method and level of tagging mortality and to range from 59 percent to 76 percent for the separate tagging seasons—astonishingly high rates in any event, and certainly not substantiated by the history of the mackerel fishery. In its early years, old fish predominated in the catch. Preliminary age studies showed it possible to follow age classes at least through the seventh year. This would hardly be the case in even a virgin fishery subject to natural mortality on the order of 65 to 70 percent. Similarly high rates of natural mortality result when Central and Lower California lots are considered in conjunction with the Southern California lots. For example, by taking the Southern California releases in the three seasons, the northern Lower California, central Lower California and 1941 Monterey lots and pooling them, giving each region equal weight, we find μ_2 to be about 8 percent; m , 13 percent; and n , 64 percent at the 40 percent level of tagging mortality.

The rates were apparently distorted by a complexity of factors. First, there were too few returns in relation to the number of tagged fish. Underestimation of tagging mortality and of recovery efficiency may be the explanation, but incomplete dispersion of tagged fish and an unequal distribution of tagging both as to place and time must be considered, as must the question of fishing effort and size of the catch. The measures of tagging mortality are admittedly inadequate. However, the end results are altered but little when the 40 percent correction is substituted for the minimal 23 percent, and it is thought unlikely that an average mortality in excess of 40 percent was suffered by any sizeable group of marked fish used in this study. While the weighting factors give a minimal estimate of the actual number of tagged fish recaptured, this error in itself cannot be held accountable unless it greatly exceeds the bounds indicated by the tests of tag loss in the canning lines. For example, if the weighted returns from the 1940-43 releases are assumed to underestimate actual recaptures by one-third, and total weighted recoveries from the three tagging seasons are adjusted accordingly, the best estimate of μ_2 becomes 35 percent and annual natural mortality, n , is 57 percent at the 40 percent level of tagging mortality. This correction for additional tag loss is roughly equivalent to assuming an average magnet efficiency for all plants of from 45 to 50 percent, which approximates the values obtained from the double-tagging experiments.

The effect of unequal distribution of tagging is undoubtedly a factor, and one for which there is no means of correction. An inequitable distribution of tagged fish in the population caused by this unequal distribution of releases and by migration to and from the fishing grounds appears to be a fundamental source of error. By using only Southern California tag lots, it was felt that the effects of incomplete dispersion would be minimized. Elimination of the Monterey and Lower California lots safeguarded against artificially low rates of decline which would result from a gradual immigration of fish released in those regions. That the fish marked in Southern California were widely scattered on the fishing

grounds is attested by the recovery of tags throughout the ensuing seasons. The returns in Central California of fish tagged in Southern California during the southern fishing season show that a certain proportion were distant from the southern area. That dispersion throughout the population was not complete at the start of season one, that, in contrast, migration from Southern California was operative both before and after the start of season one is strongly suggested by the behavior of several lots. This is especially true of those tagged during the 1941-42 season. While the rates of decline were not abnormal in these instances, the actual number recovered was very small after the zero season. It can be argued that immigration on the part of new groups, simply by cutting the chances of recovering a marked individual, might increase the apparent rate of decline without emigration. Both factors seem to have been operative.

The data suggest that the population supporting the fishery is subject to rapid changes in composition, not an untenable position in view of the widespread movements of marked fish, the broad range of the species, the limited fishing area, and the fluctuations from year to year in the total catch.

Returns were not adjusted for variations in the size of the annual catch. This could conceivably bias results based on returns from fish released in a given season. However, when calculations were based on summed returns from releases over several years—which had the effect of averaging the catch—the basic inconsistencies remained.

It is interesting to note that the difficulties encountered in the mackerel study closely parallel those which beset the sardine investigations. The question arises as to whether a practical tagging program which would provide a reliable basis for population estimates can be devised for such widespread pelagic species. More accurate measures of tag loss, both from initial mortality and from loss within the canneries might be obtained by elaborating on the methods used in the past. Marking enough individuals in enough places throughout an extended time interval to overcome the effects of incomplete dispersal would remain a huge task. It was not accomplished in this instance despite an intensive effort in 1940 and 1941 chiefly because enough men and boats were not available. Even if a theoretically perfect program were physically possible, we would have no assurance for a matter of years that the many sources of error had been overcome. The assumptions and corrections with which the study is fraught, coupled with the amount of labor and money involved, make the use of tag returns seem a dubious approach at best.

SUMMARY

The Pacific mackerel (*Pseudomacrus diego*) ranges from the Gulf of Alaska into the Gulf of California, is abundant off Southern California and much of Lower California, but is fished intensively only in Southern California waters. A tagging program was devised in 1935 to determine the extent of migration and was later used as a potential means of studying abundance.

At the close of the program in 1943, a total of over 76,000 fish had been marked, some 62,000 with internal "belly" tags and the balance with opercular tags. Both types were made of metal, the chief means of recovery being electromagnets installed in cannery reduction plants.

The opercular tag did not remain in place for a sufficient length of time to permit long-term studies and was largely replaced by the internal type.

Measures of tag-loss in reduction plants obtained from tests made as part of the sardine tagging program were used to weight returns. These measures were to some degree an underestimate, as a number of tags were known to be lost in the canning plants proper. Tests to measure this loss did not prove practicable.

Efforts were made to determine mortality caused by the tagging operation. It was not possible to conduct exhaustive tests, but those carried out pointed toward a death rate between 23 and 40 percent.

Successful tagging was accomplished in Central and Southern California and in Mexican waters as far south as San Roque Bay, about half way down the Lower California peninsula. The Fisheries Research Board of Canada marked a few individuals off the Oregon coast.

Tag returns demonstrated an interchange of fish throughout the region covered by the program. One of the eleven fish tagged off the Oregon coast was recaptured off Southern California. Fish released in Central California were recovered in large numbers at Los Angeles and Newport Beach canneries, one was recovered at San Diego and another at Ensenada, Mexico. Fish marked in Southern California appeared in numbers at Monterey and San Francisco, and there were returns at San Diego, Newport Beach, Los Angeles Harbor, Monterey, and San Francisco from northern and central Lower California taggings.

There was no indication of differential size movements except on the part of fish released in Central California. Here, large fish tended to move into Southern California waters one season in advance of small fish.

Returns from the southernmost regions in which fish were tagged were relatively few, and indicated that areas south of Thurloe and San Roque Bays, Lower California, contributed little to the California fishery.

The use of tag returns as measures of abundance did not prove feasible due to fundamental errors. These were caused by the effects of migration and incomplete dispersion of tagged fish. The lack of sufficiently accurate measures of tagging mortality and tag loss were contributory factors.

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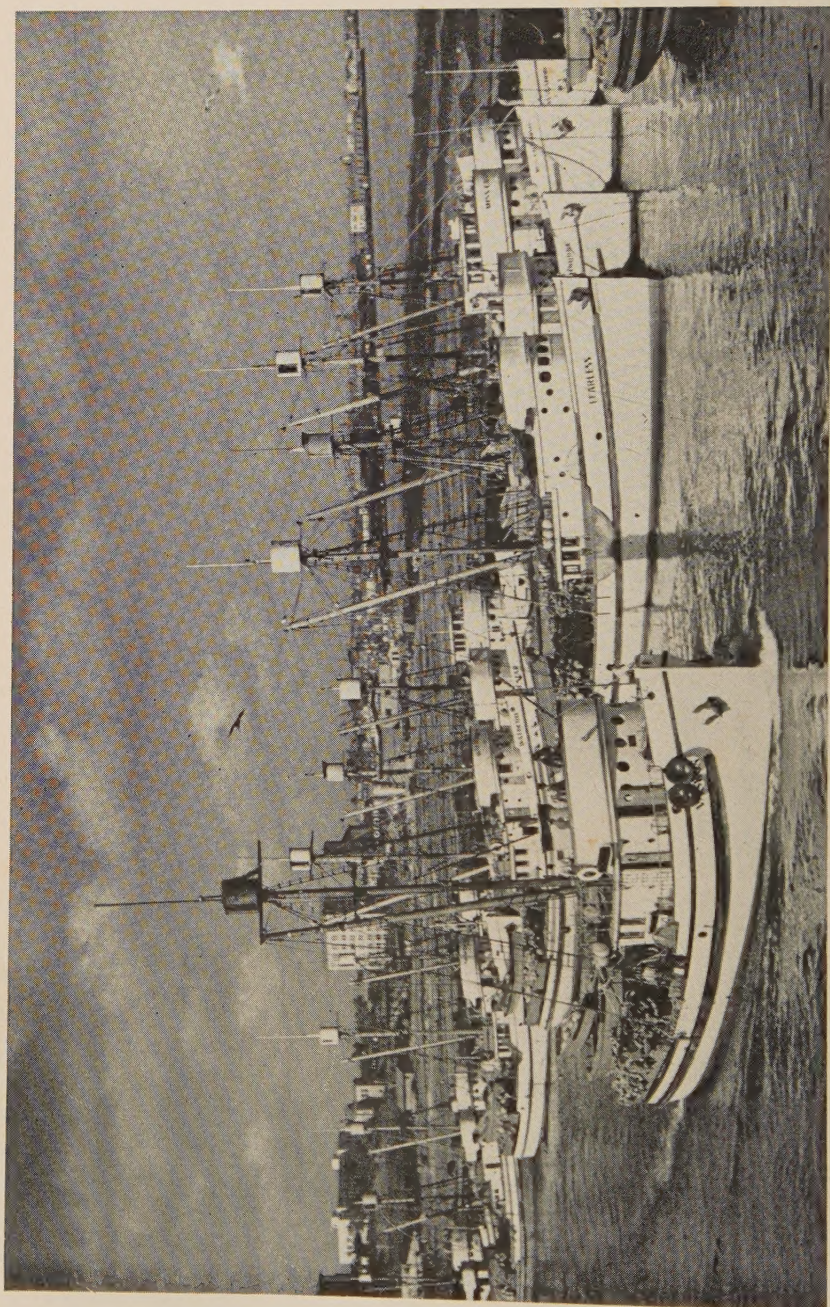


FIGURE 1. Purse seiners at San Pedro. Photograph by Vernon M. Haden, 1947